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16. ABSTRACT

Volume III of a three volume annual report/contains detailed scientific and technical information on the results of chemical and physical investigations of the operating Buccaneer Oil Field off Galveston, Texas. The tasks of the various work units are identified as follows: To identify and document the extent and types of biological, chemical, and physical alterations in the marine ecosystem that are associated with the development of and production of discharges from an oil field; to describe the fine sediments and nepheloid layer of the oil field, focusing upon their relationship to heavy metal adsorption; to determine levels, pathways, and bioaccumulation of heavy metals; to describe seasonal circulation patterns in the oil field; to determine the specific pollutants, their quantity and effects on the various components of the marine ecosystem; to determine levels, pathways, and bioaccumulation of selected discharge constituents (non-metals) in the marine ecosystem in the oil field; and to construct a hydrocarbon model. (Sinha - OEIS)

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VOLUME III - CHEMICAL AND PHYSICAL INVESTIGATIONS

A report to the Environmental Protection Agency on work conducted under provisions of Interagency Agreement EPA-IAG-D5-E693-EO During 1977-1978

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GUIDE TO USERS

This Annual Report is printed in three separate volumes:

Volume I - Synopsis

Volume II - Data Management and Biological investigations

Volume III - Physical and Chemical Investigations

Volume I is designed to be used as a briefing document and as a key to more detailed scientific and technical information contained in Volumes II and III. Objectives, methods and results for each work unit are summarized in greatly abbreviated form within Volume I to facilitate dissemination of information. Thus, Volume I can be used alone or as a reference to companion Volumes II and III. Complete citations for literature cited in Volume I can be found in the Volumes II or III in which the detailed work unit reports are presented.

It is hoped that such an approach to environmental impact information dissemination will make the Annual Report a more useful and widely read document.

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FOREWORD

Increased development of the Federal outer continental shelf (OCS) in the Gulf of Mexico is expected as the U. S. attempts to reduce its dependency on foreign energy supplies. To obtain information concerning the environmental consequences of such development, the Federal Government is supporting major research efforts on the OCS to document environmental conditions before, during, and after oil and gas exploration, production, and transmission. Among these efforts is the Environmental Assessment of the Buccaneer Oil and Gas Field in the Northwestern Gulf of Mexico, a project funded by the Environmental Protection Agency (EPA) through interagency agreement with the National Oceanic and Atmospheric Administration (NOAA) and managed by the National Marine Fisheries Service (NMFS), Southeast Fisheries Center (SEFC), Galveston Laboratory in Galveston, Texas. Initiated in 1975, it was planned as a 5-year project which is now in its third year. Its major products are annual reports of findings, which are disseminated by the National Technical Information Service, data files disseminated by the Environmental Data and Information Service, and research papers written by participating investigators and published in scientific journals. Results are also made available through EPA/NOAA/NMFS project reviews, workshops and conferences attended by project participants, and various governmental, private, and public user groups.

Objectives of the project are (1) to identify and document the types and extent of biological, chemical and physical alterations of the marine ecosystem associated with Buccaneer Oil Field, (2) to determine specific pollutants, their quantity and effects, and (3) to develop the capability to describe and predict fate and effects of Buccaneer Oil Field contaminants. The project uses historical and new data and includes investigations both in the field and in the laboratory. A brief Pilot Study was conducted in the fall and winter of 1975-76, followed by an extensive survey in 1976-77 comparing the Buccaneer Oil Field area with adjacent undeveloped or control areas. In 1977-78, investigations were intensified within Buccaneer Oil Field, comparing conditions around production platforms, which release various effluents including produced brine, with those around satellite structures (well jackets) which release no effluents. Third-year studies around Buccaneer Oil Field structures are focusing on (1) determining concentrations and effects of pollutants in major components of the marine ecosystem, including seawater, surficial sediments, suspended particulate matter, fouling community, bacterial community, and fishes and macro-crustaceans, (2) effects of circulation dynamics and hydrography on distribution of pollutants, and (3) mathematical modeling to describe and predict sources, fate and effects of pollutants.

This project has provided a unique opportunity for continued study of effects of chronic, low-level contamination of the marine ecosystem associated with oil and gas production in an established field. In many respects, it represents a pioneering effort. It has been made possible through the cooperation of government agencies, Shell Oil Company (which owns and operates the field) and various contractors including universities and private companies. It is anticipated that the results of this project will impact in a significant way on future decisions regarding operations of oil and gas fields on the OCS.

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LIST OF REPORTS AND PUBLICATIONS

Finucane, J. H. 1977. Ichthyoplankton of the Buccaneer Oil Field off Galveston, Texas Paper presented at the Fourth Biennial International Estuarine Research Conference, Mt. Pocono, Pa. (abstract published in proceedings).

Gallaway, B. J., R. Howard, K. Green and L. Martin. 1976. A study plan for the Buccaneer Oil Field assessment program. A report to NMFS from LGL, Limited-U.S., Inc., Bryan, Texas, 69 pp.

Harper, D. E., Jr., R. J. Scrudato and C. S. Giam. 1976. A preliminary environmental assessment of the Buccaneer Oil/Gas Field (Pilot Study of the Buccaneer Oil Field: benthos and sediments). A final report from Texas A&M University to the National Marine Fisheries Service, Galveston, Texas (contract No. 03-6-042-35110), 63 pp. plus appendices.

Jackson, W. B. (Editor). 1977. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1976-1977. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO, 759 pp. NTIS Accession No. PB283890.

Jackson, W. B., K. N. Baxter, C. W. Caillouet. 1978. Environmental assessment of the Buccaneer Oil and Gas Field off Galveston, Texas: An Overview. Contribution No. 78-20G, NMFS/SEFC Galveston Laboratory. Proceedings Offshore Technological Conference, May 1978, Houston, Texas, OTC 3081: 277-284.

Middleditch, B. S. and B. Basile. 1976. Deuteriated analogs as internal standards for the quantitation of environmental alkanes by gas chromatography. Analyt. Letters, 9: 1031-1034.

Middleditch, B. S., B. Basile, and E. S. Chang. 1977. Environmental effects of offshore oil production: alkanes in the region of the Buccaneer Oilfield J. Chromatography, 142 (1977): 777-785

Middleditch, B. S., B. Basile, and E. S. Chang 1978. Discharge of alkanes during offshore oil production in the Buccaneer Oilfield. Bull. Environm. Contam. Toxicol., 20: 59-65.

Middleditch, B. S. and B. Basile. 1978. Alkanes in surficial sediments from the region of the Buccaneer Oilfield. J. Chromatography 158(1978): 449-463.

Middleditch, B.S., B. Basile and E. S. Chang. 1979. Alkanes in seawater in the vicinity of the Buccaneer Oilfield. Bull. Environm. Contam. Toxicol. 21: 413-420.

Middleditch, B. S., E. S. Chang and B. Basile. 1979. Alkanes in plankton from the Buccaneer Oilfield. Bull. Environm. Toxicol. 21. 421-427.

National Marine Fisheries Service. 1977. Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico, A Report of NMFS/LGL/ Workshop I, 1977-1978. NMFS Galveston Laboratory, Southeast Fisheries Center, NOAA, USDOC. Project Number EPA-IAG-D5-E693-EO.

Wheeler, R. B., R. R. Schwarzer and J. B. Anderson. 1978. Assessment of environmental impact of offshore production in the Buccaneer Oil Field: sedimentologic and geochemical results. Proceedings Offshore Technological Conference, May 1978, Houston, Texas, OTC 3082: 235-290.

Dissertation and Theses Based Upon Buccaneer Oil Field Research:

Brenda Basile, Ph.D. Dissertation, University of Houston, 1978. Environmental Effects of Offshore Oil Production.

Evelyn S. Chang, M. S. Thesis, University of Houston, 1978. Sterols in the Marine Food Web.

INTRODUCTION

Location of Study Area

The area selected for study is the operational Buccaneer Oil Field located approximately 49.6 kilometers (26.8) nautical miles), from the Galveston Sea Buoy south southeast to production platform 296-B off Galveston, Texas (Figure 1). This field was selected as the study area because: (a) the field had been in production for about 15 years, which time had allowed full development of the oil-field-associated marine communties; (b) it was isolated from other fields which facilitated the selection of an unaltered area (for comparison) within a reasonable distance of the field; (c) it produced both oil and gas that represented a major portion of the pollutants from marine mineral extraction; (d) its location simplified logistics and reduced the cost of the research; and (e) the Texas offshore area had not been fully developed for gas and oil production but was expected to experience accelerated exploitation in the future.

Oil Field Operation History

The Buccaneer Oil Field was developed by the Shell Oil Company in four blocks of land that were leased in 1960 and 1968 as follows:

Year	Lease Number	Block Number	Acreage	Hectares
1960	G0709	288	2,790	1,129
1960	G0713	295	4,770	1,930
1960	G0714	296	4,501	1,821
1968	G1783	289	2,610	1,056

In the development of the field, 17 structures have been built; two are production platforms, two are quarters platforms, and 13 are satellite structures surrounding well jackets. Initial exploratory drilling began about mid-summer of 1960 with mobile drilling rigs. When (as the result of the exploratory drilling) the proper locations for platforms were selected, permanent platforms were constructed.

There has been no reported history of major oil spills from this field. Although there undoubtedly have been losses of from a barrel of oil upward because of the mechanical failure of various pieces of equipment, there have been no major oil spills, the largest spill being three barrels in 1973. The reported oil spill chronology and quantity for Buccaneer Field was as follows:

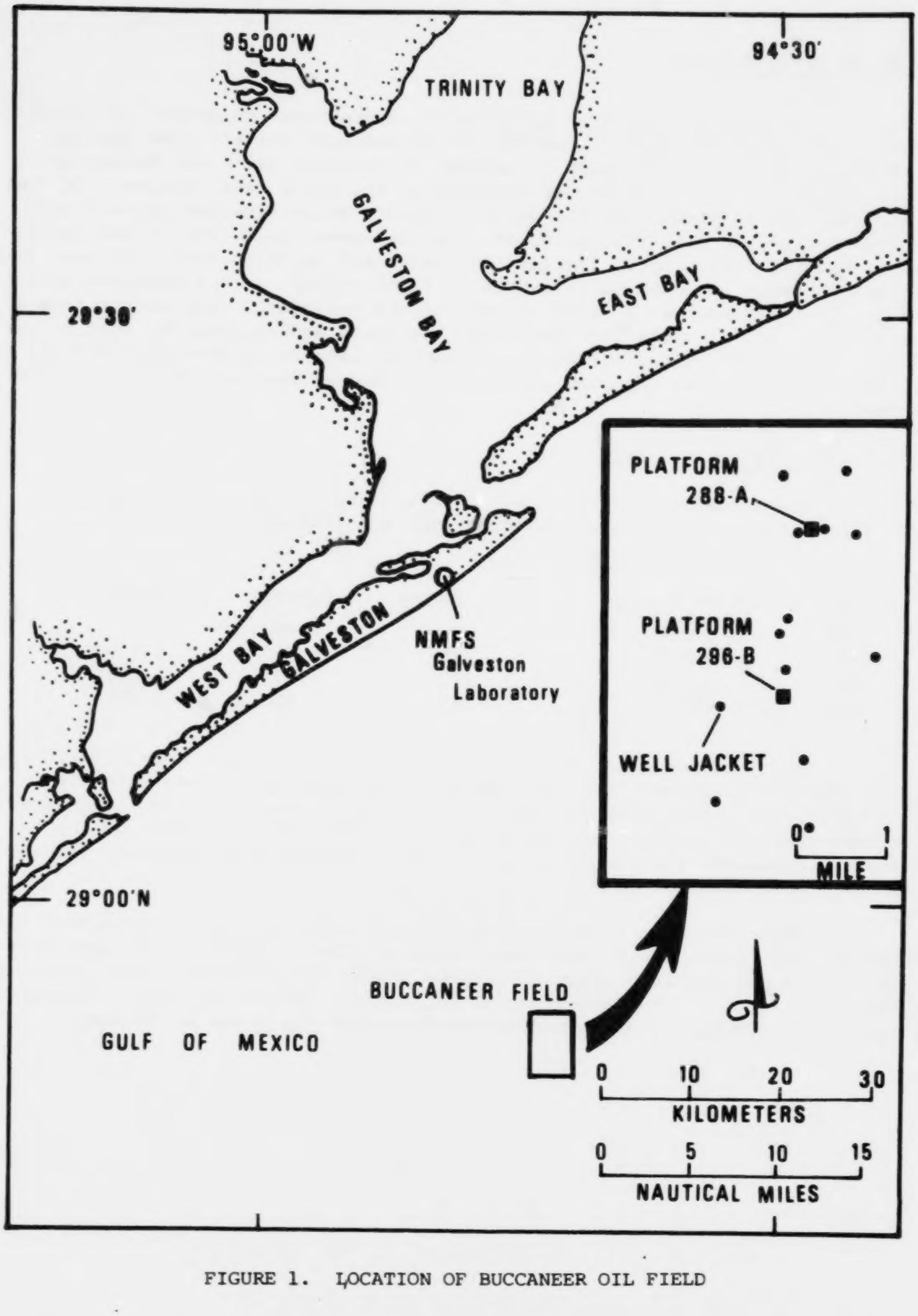
95°00'W
94°30'
TRINITY BAY
GALVESTON BAY
EAST BAY
29°30'
PLATFORM
288-A
PLATFORM
296-B
WELL JACKET
0
1
MILE
WEST BAY
GALVESTON
NMFS
Galveston
Laboratory
29°00'N
BUCCANEER FIELD
GULF OF MEXICO
0
10
20
30
KILOMETERS
0
5
10
15
NAUTICAL MILES

FIGURE 1. LOCATION OF BUCCANEER OIL FIELD

Date	Source	Amount Barrels	 Liters
September 1973	Platform 296-B	0.5	79
November 1973	Unknown	3.0	477
July 1974	Platform 296-B	0.5	79
August 1974	Platform 296-B	1.7	265
September 1975	Platform 288-A	0.2-0.4	38-56
Totals		5.9-6.1	938-956

The Buccaneer Oil Field first began operations with the production of oil. Later, when significant quantities of gas were found, the field began producing both oil and gas and has continued to do so to date.

The production platforms and satellites (well jackets) are connected by a number of pipelines with a 20-inch diameter main pipeline connecting the field to shore. All of the pipelines that are 10 inches or greater in diameter are buried. The Blue Dolphin Pipeline Company was granted a pipeline permit (No. G1381, Blocks 288 and 296) in 1965 and has operated the pipeline since its construction.

The Buccaneer Oil Field occupies a limited area (about 59.3 km^2; 22.9 sq. statute miles) leased in the northwestern Gulf of Mexico. Because of the geographically small size of this area and because major environmental similarities occur over much of the western Gulf of Mexico, it is anticipated that the results of the proposed studies can be extrapolated, to some extent, to other areas off the Texas coast where oil fields occur or will be developed in the foreseeable future.

Four types of structures located in Buccaneer Oil Field (production platform, quarters platform, satellite (well) jacket, and flare stack), to be referred to in this report, are shown in Figure 2, which is an oblique aerial photograph of production platform 288-A and vicinity within Buccaneer Oil Field. A map of Buccaneer Oil Field, (Figure 3) depicts the locations of platforms and satellite jackets within the field. Table 1 is a key to designations used by each work unit and by Shell Oil Company for these locations.

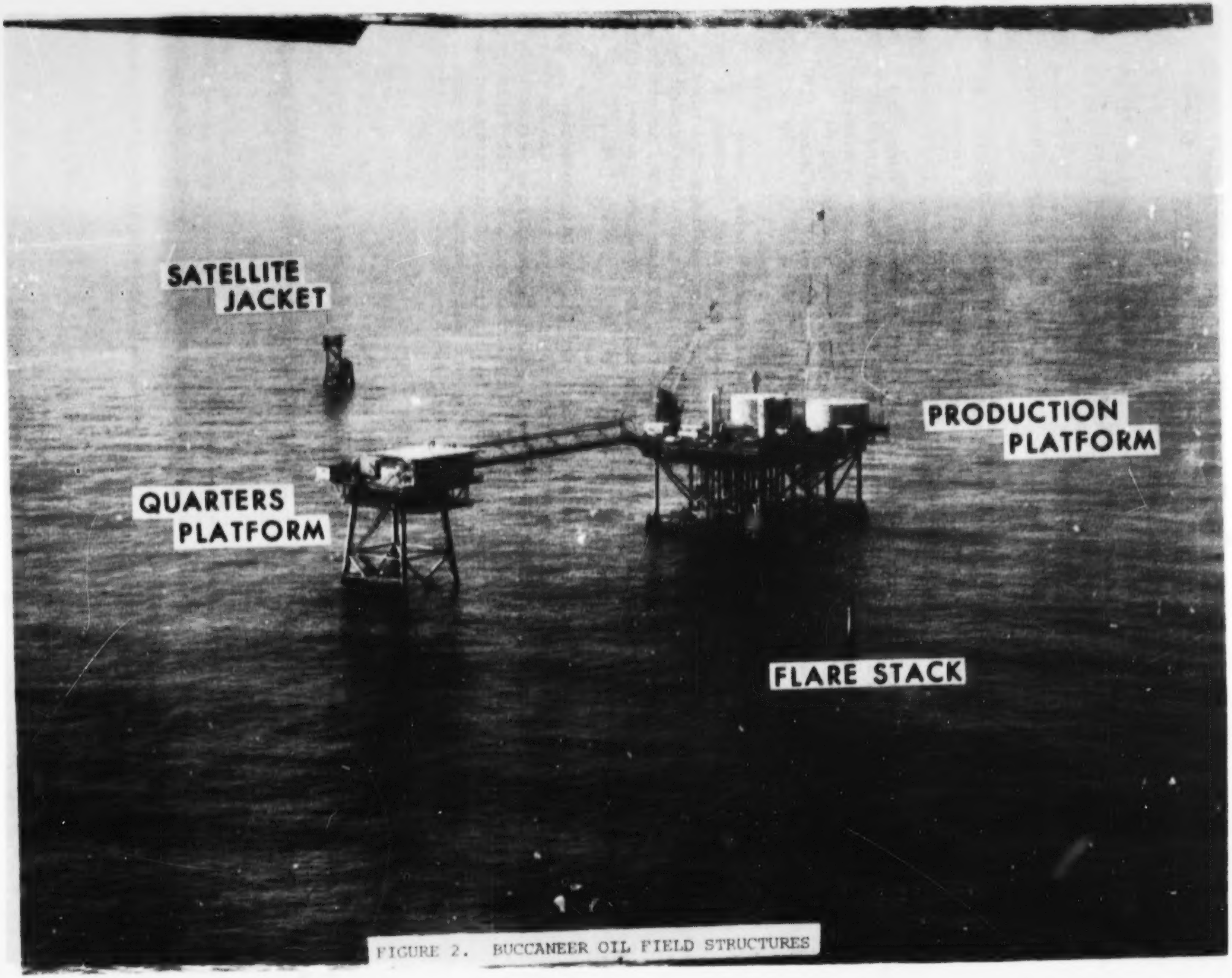
SATELLITE JACKET
QUARTERS PLATFORM
PRODUCTION PLATFORM
FLARE STACK

FIGURE 2. BUCCANEER OIL FIELD STRUCTURES

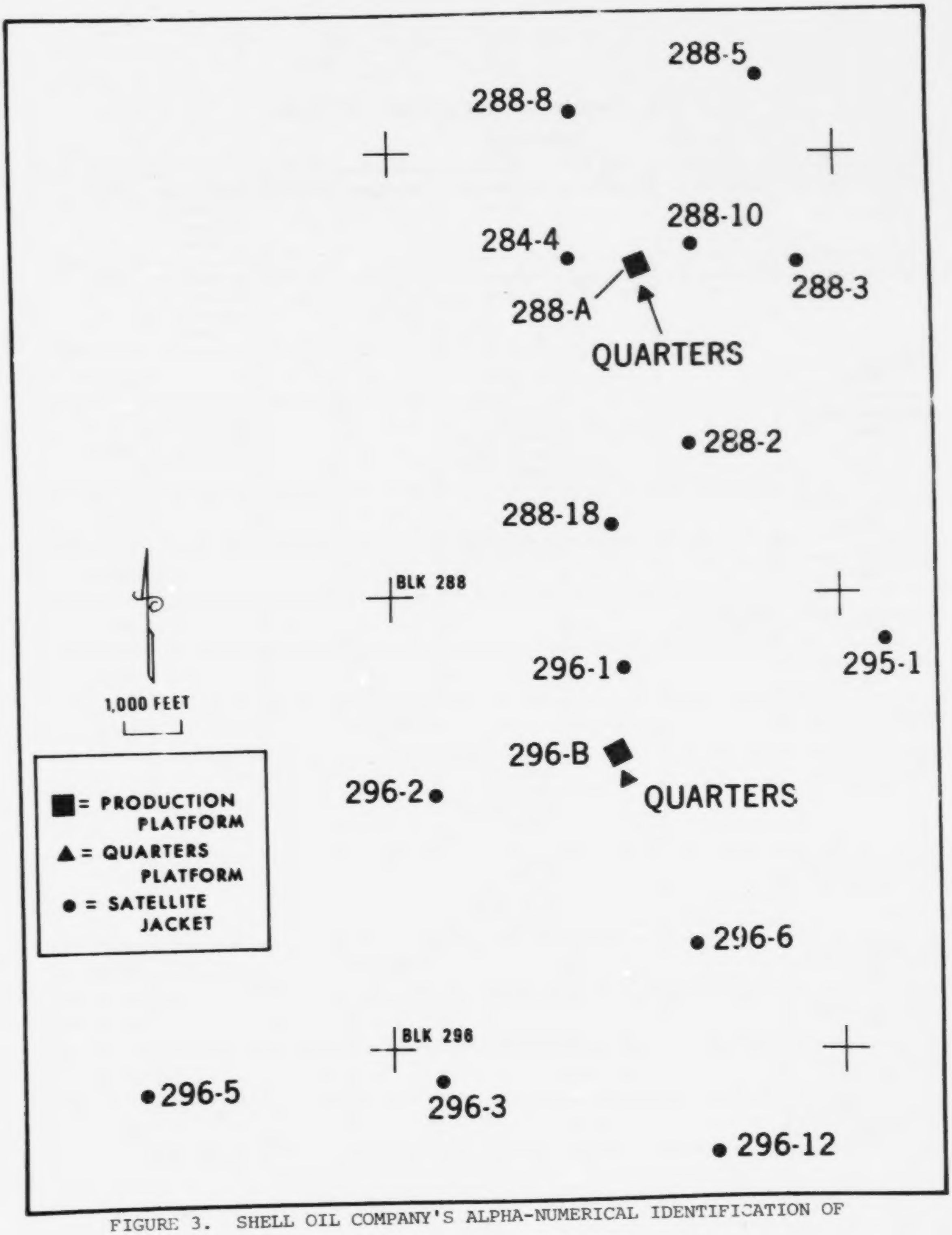
288-5
288-8
288-10
284-4
288-3
288-A
QUARTERS
288-2
288-18
BLK 288
295-1
296-1
1,000 FEET
296-B
QUARTERS
296-2
■ = PRODUCTION PLATFORM
▲ = QUARTERS PLATFORM
● = SATELLITE JACKET
296-6
BLK 296
296-5
296-3
296-12

FIGURE 3. SHELL OIL COMPANY'S ALPHA-NUMERICAL IDENTIFICATION OF BUCCANEER OIL FIELD STRUCTURES

TABLE 1. PLATFORM AND SATELLITE KEY: 1977-1978

	WORK UNITS						
Shell Oil Company	2.3.2/ 2.4.2	2.3.4	2.3.5	2.3.6	2.3.7	2.3.8	2.4.1
Platform 288-A	Platform A or A	Platform A	Platform A or A	Platform "A"	Platform A	Production Platform & Quarters 288-A	pfm A
Platform 296-B	Platform B or B	Platform B	Platform B or B	Platform "B"	Platform B	Production Platform & Quarters 296-B	pfm B
Satellite Jacket 288-8							jkt A
Satellite Jacket 288-5			Control 288-5, C or Well Jacket 288-5			Satellite 288-5 or Satellite	jkt B
Satellite Jacket 288-4							jkt C
Satellite Jacket 288-10							jkt E
Satellite Jacket 288-3	Satellite Structure S						jkt F
Satellite Jacket 288-2							jkt G
Satellite Jacket 288-18				Satellite "N"			jkt H
Satellite Jacket 296-1			Control 296-1 or Well Jacket 296-1				jkt I
Satellite Jacket 295-1			Control 295-1 or Well Jacket 295-1				jkt J
Satellite Jacket 296-2				Satellite "S"			jkt K
Satellite Jacket 296-3							jkt M
Satellite Jacket 296-12							jkt N
Satellite Jacket 296-6							jkt O

Work Unit 2.3.2/2.4.2 Describe the Fine Sediments and Nepheloid Layer of the Oil Field, Focusing Upon their Relationship to Heavy Metal Adsorption/Determine Levels, Pathways, and Bioaccumulation of Heavy Metals in the Marine Ecosystem in Oil Field

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ABSTRACT

The Buccaneer Oil/Gas Field is a dynamic, passive sedimentary environment in which relict Pleistocene deposits are presently exposed over much of the seafloor. Redistribution of sediments, particularly around production structures, is the most active depositional process. Suspended sediments consist of the remains of organisms which live on or around production structures, and terrigenous sediment resuspended from the bottom.

Of the trace metals analyzed in this report (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr, Zn) only Ba, Pb, Sr, and Zn appear to be present in concentrations significantly above background and only within 180 meters of the drilling structures. The apparent anthropogenic sources of the Ba, Pb, Sr, and Zn are probably a combination of drilling muds, produced formation waters and corrosion of the drilling structures. Another possible source for Pb is the combustion of leaded gasoline by pleasure boats. Suspended sediments are enriched in trace metals as compared to surficial sediments.

The accumulation of trace metals in fish muscle and liver, barnacles, and various benthonic organisms living in the Buccaneer Oil/Gas Field was determined. Whether or not they contain significantly higher concentrations of trace metals is difficult to say because of the lack of similar data from control areas.

Editors Note:

In a letter dated May 12, 1978, to Dr. Charles W. Caillouet, Mr. J. A. Burgbacher, Shell Oil Company, New Orleans Louisiana, questioned the following statement (page 114) and Figure 26 (page 170) made by Dr's John Anderson and Rudy Schwarzer in Jackson (1977): "It is evident from the magnetic survey that many of the pipelines have been systematically displaced from their original positions. This means that the pipeline map of this field is invalid. Perhaps this also means that a periodic revalidation of pipeline maps for all offshore oil fields is in order."

Mr. Burgbacher offered the following: "On March 5, 1976, we transmitted a flowline map of the Buccaneer Field which had been revised in June 1976. The NMFS's report dated August, 1977 covering the period 1976-1977 and your OTC paper [Jackson er al, 1978] noted that, according to the magnetic survey, some of the flowlines had been displaced upwards to 100 meters. Originally it was thought that this apparent displacement could be attributed to the lack of control at the time that these lines were laid. Upon review by our Land Department, the techniques employed by Rice University were determined to be insufficiently accurate to establish the true location of the lines.....Also attached is a 1976 revision of the flowline map. You will note that the location of several lines, including some which according to your investigators had the greatest displacement, were verified by buoys attached to the lire or to the shellfish and visual triangulation."

Literature Cited:

Jackson., W. B. 1977. (Editor). Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico, 1976-1977. NOAA Annual Report to EPA. NMFS/SEFC Galveston Laboratory, Galveston, Texas. 759 pp. National Technical Information Service Assession No. PB283890.

Jackson, W. B., K. N. Baxter and C. W. Caillouet. 1978. Environmental Assessment of the Buccaneer Oil and Gas Field off Galveston, Texas: An Overview. In: Proceedings of the Offshore Technological Conference, Paper No. 3081, Houston, Texas. pp. 277-284.

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PART A

BOTTOM SEDIMENTS AND SUSPENDED SEDIMENTS

PART A: BOTTOM SEDIMENTS AND SUSPENDED SEDIMENTS

I. Introduction

Within the marine environment, contaminants introduced into the water column will likely be absorbed or adsorbed by sediments. Hence, the uptake and dispersal of contaminants will be governed, in large part, by sedimentary processes. Results from the first year's investigation in the Buccaneer Field showed that trace metals and hydrocarbons were, in fact, concentrated in bottom sediments near (within approximately 200 feet) production structures (Anderson and Schwarzer, 1977; and Middleditch, 1977). This implies that sediments are providing an important transport mechanism and sinks for oil field contaminants.

For sedimentation of oil to occur, the specific gravity of petroleum residues must be increased to greater than 1.025, the specific gravity of seawater. This is accomplished by:

a) absorption or adsorption onto suspended particles.

b) sorption of dissolved species into suspended sediment.

c) increases in specific gravity due to evaporation and dissolution (Wheeler, 1977).

Most workers agree that absorption and/or adsorption onto suspended particles is the primary mechanism (Di Salvo and Guard, 1975; Meyers and Quinn, 1973; and Meyers, 1976). Due to their large surface area/volume ratios and their electrochemical properties, clays have the greatest sorption capabilities of any material in the sedimentary spectrum (Wheeler, 1977), different clay minerals having different sorption capacities.

Also, Hargrave and Phillips (1975) found that the highest concentrations of petroleum hydrocarbons were associated with silt-sized sediment in Bedford Basin, Nova Scotia. Sediment settling velocities, which is largely a function of size, will also control rates of suspension, and hence sediment-chemical reactions.

Once sedimented, petroleum residues and sorbed hydrocarbons can persist for years in the sediment in a dynamic, yet slow state of degradation (Meyers, 1976). In a similar manner, trace metal contaminants introduced into the marine system will most likely be absorbed or adsorbed by fine detrital sediment or complexed by organic material.

As with hydrocarbons, the rate of uptake of trace metals by suspended sediment is determined by suspension rates and the nature of material in suspension. The uptake and dispersal of these contaminants, and their ultimate removal from the aquatic environment through sedimentation is determined by:

a) the circulation dynamics of the environment.

b) the size, quantity and composition of suspended material.

c) sedimentation processes and rates.

d) resuspension due to physical and biological processes.

A. Purpose

The Buccaneer Field is a highly complex sedimentary system in which exposures of ancient sediments at the seafloor, winnowing near rigs, and normal marine agents all contribute to the highly variable lithologies observed there (Anderson and Schwarzer, 1977). This complex sedimentologic setting is such that geochemical interpretation must be based on sediments displaying similar textural characteristics, particularly with regard to fine sized material.

One of the objectives of our sedimentologic investigation was to conduct sediment size and geochemical analyses of additional sediment samples taken near production platform A and one well jacket. Both surface and subsurface samples were analyzed in order to enable background geochemical and size determinations.

A second objective has to do with suspended sediment geochemistry and dynamics within and around the Buccaneer Oil/Gas Field. This portion of the project was aimed at answering two questions.

1) Do suspended sediments within the Buccaneer Field contain abnormal concentrations of those trace metals analysed in this project (Ba, Cu, Cr, Cd, Co, Fe, Hg, Mn, Ni, Pb, Zn, Sr)?
2) Would contaminated suspended sediments likely come to rest on the seafloor within the field area, or will they be transported some distance from the field? This important question can, in part, be resolved by establishing the settling characteristics of suspended sediment samples in the laboratory.

B. Previous Work

The character of bottom sediments within the Buccaneer Oil Field and the sedimentary processes active there are described by Anderson and Schwarzer (1977). As for suspended sediments, a number of investigators have dealt with suspended sediment dynamics in the Gulf of Mexico.

Shideler (1978) recognized a near-bottom suspended sediment layer in the northwestern Gulf of Mexico. He concluded that these sediments were derived, in large part, from estuaries and that their dispersal is governed by drift currents, wave surge and storm tides. Undoubtedly, Shideler's observations are correct, however, such broadly based inferences merely reflect the state of the art with regard to suspended sediments.

The type and quantity of sediment discharged into the Gulf of Mexico by rivers and estuaries is controlled by precipitation and drainage rates. Other important parameters include wind speed and direction and thermohaline wedging within coastal water bodies (Anderson and Broekstra, 1977).

Once suspended sediments are introduced into the gulf, their dispersal is dependent upon circulation dynamics within the region and the degree of density stratification within the water column. Temperature induced density gradients in surficial waters over continental shelves constitute an important obstacle to sediment diffusion. Thermoclines with only a 0.1^{o}c change are commonly the locus of major concentrations of suspended matter (Drake, 1971) and moving water bodies with temperatures of only 1.0^{o}c greater than ambient temperature are capable of displacing very turbid bottom water off the bottom (Anderson and Broekstra, 1977).

The degree to which circulation of inner shelf waters influences sediment dispersal patterns along the Texas coastline was investigated by Hunter (1973 and 1976) using Environmental Resource Technology Satellite (ERTS) imagery. He observed strong longshore, offshore and counterclockwise components of turbid water movement in response to changing wind patterns. His satellite data show how rapid changes in bottom water turbidity would occur within the field area as turbid water masses move about in response to changes in the wind field.

In addition to wind driven currents, wave and tidal mechanisms may also influence turbid water distribution, but these processes are poorly understood. McGrail and Rezak (1977) have suggested that internal waves may be important in maintaining the nepheloid layer of the northwestern Gulf of Mexico outer continental shelf. Again, the influence of this mechanism at shallower depths on the shelf has not been fully investigated. Lastly, resuspension of fine sediments within the field area is known to occur (Anderson and Schwarzer, 1977). Continuous resuspension of fine sediments within the field area is probably quite significant.

As for the composition of suspended sediments within the field area, little was known prior to this investigation. Manheim et. al. (1972) analyzed suspended sediment samples from surface water stations of the northern Gulf of Mexico. They found that suspensates from areas farther than 100 km from shore contained mainly combustible organic matter, part of which was attributed to living plankton. The mineral composition of surface suspensates from the Texas region were found to consist of montmorillonite - kaolinite mixtures with montmorillonite being most abundnat. One of their sample profiles passed very close to the Buccaneer Field and is shown in figure 1. Their data show a very sharp boundary between the Galveston Bay sediment plume, with total suspensates of greater than 15 mg/l suspended sediment, and offshore waters.

II. Methods and Materials

A. Sampling Procedure

Bottom samples were obtained using a large gravity corer. Small sediment cores were taken around platform A and the satellite platform by divers using 3.5 cm diameter plastic tubes. Cores were extruded, split longitudinally and described before sampling. Longer piston cores (up to 1.5 meters long) were obtained at eight sights within the field for subsurface analyses. Piston cores were extruded, split and described in the same way as smaller cores.

Suspended sediments were collected using sediment traps. Initially large traps (35 cm inside diameter) were used. Two sets of traps (one Polyvinal chloride (PVC) set and one galvinized steel set) were made so that separate samples could be obtained for hydrocarbon work, using metal traps; and trace metal work, using plastic traps. Later it was decided to use smaller plastic traps because sedimentation rates proved to be higher than anticipated and because it was decided that PVC traps did not offer a significant undetectable hydrocarbon source.

The first set of traps were placed under platform A on 11/3/77 at 4.5, 12.0 and 18.5 meters water depth. On that same day the brine discharge on platform A was turned off. On 11/13/77 the traps were moved from platform A to platform B. During this period the bottom trap collecting tube had completely filled with sediment. During the latter part of November and December severe weather conditions prevented us from recovering the traps. In January, it was discovered that all of the traps had been destroyed. No sediment was recovered and we began constructing new, more durable sediment traps.

A diagram of the trap now being used in this study is shown in figure 2. It is constructed of PVC; has a 16cm inside diameter, 35cm long collecting tube, and is attached directly to the legs of the structure. Sediment traps were placed at approximately 4.5, 12.0 and 18.5 meters water depth on both platform B and a satellite structure. The first sample period for the new traps, which lasted from 5/26/78 until 6/21/78, proved to be highly successful.

B. Analytical Procedure

A 3 to 5 gram sediment sample was thoroughly homogenized and a small (0.3 to 0.5 gram) subsample removed for hydrophotometer analysis. The remaining sample was dried at 40°C and weighed. It was then dispersed over a 24-hour period in Calgon solution.

The dispersed sample was wet-sieved at 63μ using deionized water. The <63μ fraction (silt and clay) was recovered in a plastic flask and the >63μ (gravel and sand) fraction was dried and weighed. the >2mm (gravel) fraction was then removed, using a 2mm sieve, and weighed. The 63μ to 2 mm (sand) fraction was split using an Oddo microsplitter and a 200mg sample analyzed using the large settling tube.

The washed supernatant from wet sieving was covered and allowed to settle for approximately one hour. The fines that remained in suspension after one hour were siphoned-off and the remaining material was washed into decanting tubes. The sample was then decanted repeatedly until all of the <16μ fraction was removed. The remaining decanted sample (16μ to 63μ) was dried, weighed and analyzed using the small settling tube.

The fine-silt-clay fraction (1.0μ to 16μ) was analyzed using a small (0.3 to 0.5 grams) subsample that has not been dried. The sample was allowed to disperse in deionized water for 1-3 days. It was then analyzed by hydrophotometer, a photoextension method (Jordan, et al. 1971).

Suspended sediment samples were treated with 30% hydrogen peroxide and heated several times to remove organics. The sample was then washed with deionized water and treated with 10% hydrochloric acid until all $CaCO_3$ was removed. The remaining mineral (detrital) component was analyzed for grain size distribution using the method outlined for bottom sediment samples. The majority of samples collected in the sediment traps consisted almost entirely of organic debris so that size-analysis could not be conducted. Organic samples were analyzed microscopically to determine their composition and to look for metal debris.

C. Analytical Equipment

Sediments with grain-size distribution within the <63μ fraction play a vital role in any geochemical system. This size fraction includes material which occurs in suspension from time to time, maximizing its potential to accumulate contaminants (Wheeler et al, 1978). Determination of the <63μ fraction of sediment samples is difficult and reproducible results may be obtained only with sensitive settling velocity measurements of particles.

The instrument used to analyze for sediment size in this study is an automated system (Rice University Automated Sediment Analyser - RUASA) which is based on particle-size determination from settling velocities. The system is shown in diagramatic form in figure 3. The RUASA system consists of two settling tubes and a hydrophotometer. A large tube (140 cm long and 15 cm inside diameter) was used to analyze sand size (-1.0 to 4.0 Ø) particles and a small tube (25 cm long and 6 cm inside diameter) was used for coarse silt analyses (4.0 to 6.0 Ø). The Rice University Hydrophotometer (Jordan et. al., 1971) measures particle-size in the 6.0 to 9.0 Ø range.

Sample introduction in the large settling tube followed the method described by Gibbs (1974). Sand grains (sample size approximately 200 mg) were made to adhere to a plastic lid using a thin film of Calgon solution. The lid was then lowered onto the surface of the water column with immediate release of the sample upon contact. A remote switch was used to activate the electronic recording system and to mark the beginning of the experiment.

Decanted silt samples were introduced into the small settling tube as a slurry consisting of approximately 200 mg of sediment and 25 ml of deionized water.

The weight sensing device for both tubes consists of a Gould (Model UC3) universal transducing cell, or strain gauge, from which a weighing pan at the bottom of the tube is suspended. The output of the transducing cell is amplified using a Gould (Model SC 1105) bridge amplifier. Changes in the water temperature of the small tube are minimized by immersing it in a constant water temperature bath.

Calibration of the large tube followed the procedure described by Gibbs _et al._ (1971). Small tube calibration was accomplished by using silt samples that had been decanted within various silt size ranges with a precision of 0.5 Ø.

Upon initiation of an experiment, using an external interrupt switch, a strip chart recorder begins to plot weight versus time. Simultaneously, D.C. voltage output from the bridge amplifier enters the experiment controller consisting of (1) a timer to determine the data conversion rate, and (2) an A/D converter. The raw data are then stored in a sequential file on a data disk. A dual disk drive enables the simultaneous use of both a program disk, which contains the software necessary for gathering data, and a separate data disk. Digital voltage measurements are made at 0.5 second intervals for the large tube and at 10.0 second intervals for the small tube.

Determination of size (Ø) or settling velocity (ψ) distributions is accomplished by summing the voltage readings acquired during designated time intervals. For grain-size distributions, these time intervals correspond to 0.25 Ø grain size classes derived from Gibb's formula (Gibbs _et al_, 1971) for sand-size particles and from Oden's formula (Krumbien and Pettijohn, 1938) for silt-size particles.

Gibbs formula is given below:

$$r = \frac{0.055804V^2P_f + 0.003114V^4P_f^{\,2} + g(P_s - P_f) \quad 4.5nV + 0.008705V^2P_f}{g(P_s - P_f)}$$

where: r = particle radius in cm

n = dynamic viscosity of fluid in poises

g = acceleration of gravity (cm/sec^2)

v = velocity in cm/sec

P_f = density of fluid in g/cm^3

P_s = density of particle in g/cm^3

Oden's formula = $W = P-(\frac{td^P}{dt})$

where: W = weight of the totally settled fractions

P = weight of the pan at some time t

$\frac{d^P}{dt}$ = slope of the weight-accumulation vs. time curve

Computational data are hard-copied using a computer terminal.

Routine statistical output of the system consists of:

1) The percent gravel, sand, silt, and clay (based on dry

weight values input prior to the experiment)

2) The frequency and cumulative weight percents

3) The mean grain size, standard deviation, skewness and kurtosis

4) Digital graphic displays of frequency and cumulative size distribution curves.

Data generated from this instrument system are very reproducible with variation in mean grain size for the large tube on the order of 1% and for the small tube 5%. Reproducibility in the 4.0 to 6.0 Ø range is far superior to that obtained by pipetting. This is illustrated in figure 4 which shows frequency curves for the same sample analyzed three separate times on our RUASA system.

D. Statistical Treatment of Data

The mean grain size and standard deveiation of each sample is computed by the method of moments (Folk. 1968). This is a non-graphical method of obtaining values in which every grain in the sediment affects the measure. The phi (Ø) arithmetic mean of sample (MØ) is computed using the following formula:

$$M\text{Ø} = \frac{DW}{W}$$

where: D = the Ø midpoint for a class interval

W = the weight in grams of a class interval

Statistical determinations for the project are based on 0.25 Ø class interval measurements.

The sample standard deviation (σØ) is obtained using the following formula:

$$\sigma\emptyset = \frac{W(M\emptyset - D)^2}{W}$$

where: D = the Ø midpoint

W = the weight in grams

MØ = the sample mean

The skewness of a sample is a measure of the degree of asymmetry of the frequency curve generated by that sample. A positive skewness reflects an excess of fine material (frequency curve skewed to the right) and a negative skewness reflects an excess of coarse material (curve skewed to the left).

The kurtosis is a measure of the peakedness of the sample frequency curve. More than that, it is a measure of the ratio between sorting in the tails of the curve and the sorting in the central portion. Kurtosis values greater than 1.0 reflect a high degree of peakedness and greater sorting in the central portion of the curve than in the tails. Values of less than 1.0 reflect a lower degree of peakedness and stronger sorting in the tails of the curve.

Both skewness and kurtosis are computed using graphic methods. The Inclusive Graphic Skewness (Sk_I) is derived from the following formula (Folk, 1968):

$$Sk_I = \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{2\ (\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{2\ (\emptyset 95 - \emptyset 5)}$$

The various Ø values are taken from the sample cumulative frequency curve.

The Graphic Kurtosis (K_G) is computed using the formula:

$$K_G = \frac{\emptyset 95 - \emptyset 5}{2.44(\emptyset 75 - \emptyset 25)}$$

where again the various 0 values are obtained from the sample cumulative frequency curve (Folk, 1968).

III. Results

A. Bottom Sediments

Figures 5, 6 and 7 show the locations of samples analyzed for this years sedimentologic investigation. Statistical data including the percent gravel, sand, and mud; mean grain size; standard deviation; skewness and kurtosis for each sample are listed in table 1.

Several samples were selected from throughout the field to test variability within the field area. Figure 8 shows a sediment facies map for the field study area which has been revised from last year's map using statistical clustering techniques described in the geochemical section of this report.

In general, the field is divided into a northern portion dominated by relict Pleistocene sediments and a southern portion in which Pleistocene deposits are overlain by a thin veneer of reworked muddy sands. Sediment distribution patterns throughout the field are hence greatly influenced by apparently active structural features of the region (Anderson and Schwarzer, 1977).

The dominant lithologies within the area are:

Unit 1 - a gravel-sized calcareous shell hash which occurs in the northeastern portion of the field area.

Unit 2 - a fine silt and clay of Pleistocene Beaumont Formation.

Unit 3 - a very coarse (0.50 to 1.50), well rounded, frosted quartz sand.

Unit 4 - a very fine (3.50), very angular quartz sand.

Unit 1 - This unit is confined to the northeastern part of the field (Fig. 8). It consists of gravel-sized shell debris of which mollusk and bryzoan fragments comprise the major component.

Unit 2 - This unit is exposed in the northeastern part of the field and is in contact with Unit 1. It is overcompacted and contains a fossil foraminiferal assemblage dominated by Ammonia beccarii (Cole) and Elphidium gunteri (Linné). The overcompacted state of this clayey unit and its estuarine fossil foraminiferal assemblage along with its high clay content are typical of the Pleistocene Beaumont Formation which outcrops over vast areas of the Texas Gulf Coast. Figure 9 shows representative size frequency curves for this unit. Beaumont samples analyzed in this project are typically negatively skewed, with mean grain size higher than 7.50.

That the Beaumont Formation lies at or near the surface throughout the field area is suggested by seismic reflection profiles of the area (Anderson and Schwarzer, 1977) and by the fact that this unit is commonly exposed in the scour zones around oil field rigs. It probably serves as a major source of clays and silts for the field area.

Unit 3 - This unit occurs only within the scour zones around rigs and is stratigraphically associated with the Beaumont Formation. Individual sand grains are commonly iron stained. The heavy mineral assemblage associated with this unit has a strong ZTR (Zircon - Tourmaline - Rutile), epidote, and brown hornblende assemblage. This mineralogy is similar to that of sands from the Trinity River and is in sharp contrast to modern heavy mineral assemblages of the region (Van Andel and Poole, 1960). Also, the fossil benthic foraminifera associated with this sand comprise a low diversity population consisting dominantly of *Elphidium gunteri* (Cole), *Ammonia beccarii* (Linnè), *Hanzawaia concentrica* (Cushman), *Elphidium incertum mexicanum* (Kornfield), and *Cibicides strattoni* (Applin). This assemblage is quite similar to that which presently inhabits the high energy wave zone of the Alabama Gulf Coast (Anderson, 1968). The size, texture, mineralogy and fossil foraminifera of this sand unit suggest a high energy wave zone environment of deposition in which the Trinity River was the prime source. The Trinity River has not been an active contributor of sand to the Texas Gulf Coast since its mouth was flooded to form Galveston Bay some 3,500 years ago. Figure 10 shows representative size frequency curves for samples taken near rigs which contain varying amounts of this coarse sand. *Unit 4* - The most abundant sediment type in the Buccaneer Field consists of very fine (3.5Ø), very angular, quartz sand. The heavy mineral assmeblage of this sand varies only slightly within the field and consists dominantly of hornblende (averaging 50%), with lesser amounts of epidote and pyroxenes (averaging 15% each).

The foraminiferal assemblage found in this unit contains the following species in the average percentages given:

Elphidium gunteri(Cole)	35%
Elphidium incertum mexicanum (Kornfeld)	20%
Anomalina io (Cushman)	19%
Quinqueloculina lamarckina (d'Orbigny)	11%
Ammonia beccarii (Linnè)	10%
Elphidium discoidale (d'Orbigny)	2%

Psuedononion grateloupi (d'Orbigny)	2%
Other species which are common to the coastal waters of the Gulf Coast	1%

Figure 11 shows representative frequency curves for several selected surface sediment samples from the field area which contain these fine sands. In fact, all of the sand facies within the field area (Fig. 8) are dominated by these 3.5Ø sands. The only variation within these sandy deposits is in their silt clay content. These variations are only evident in surficial deposits, however. This is illustrated in figure 12 which shows the sand/silt/clay concentrations for selected surficial sediments within the field along with similar data for samples taken at depth in piston cores. Hence, 3.5Ø sands are also relict and the facies patterns shown in figure 8 are recent and reflect varying degrees of reworking, probably during Holocene time.

Results from the first year's investigation indicated that sediment scouring beneath and around oil field structures is an important process in the Buccaneer Field. Scour of sediments around platform piles due to current and oscillatory wave action is a well documented phenomenon (Machemhl and Abad, 1975). Obviously such scouring will seriously influence the sedimentation of contaminated particles near structures (Wheeler *et al.*,1978). Consequently, the depth and dimensions of the scour zone must be established before geochemical interpretations can be made.

Sediment cores taken in the vicinity of platform A and Satellite Structure 288-3 were used to measure the aerial extent of scour zones and the depth of scouring. The area of scouring is evident from the occurrence of reworked surficial sediments and the depth of scouring determined by mapping the horizon between reworked sediments and undisturbed ancient deposits. This surface is clearly evident in figure 13. Note that the scour zone in both cases is largest on the down current (southwest) side of the structures. If the Beaumont Formation surface is assumed to be horizontal in the general area of platform A, then scouring has removed approximately 50 centimeters of sediment from around the structure to expose this unit.

B. Suspended Sediments

During the first years investigation we began monitoring temperature and turbidity within the field area on approximately one month intervals. As a result of this pilot investigation we were able to make the following observations.

1) During summer and early fall a near-bottom suspended sediment layer frequently occurs within the field area. Suspended sediment concentrations within this layer range from 10.0 to 17.0 mg/liter and on one occasion were in excess of 30 mg/liter.

2) From October through late spring, cooling and mixing of the water column appears to dissipate this layer, although our monitoring frequency was probably too large to document this.

3) Comparisons of trace metal data from suspended sediment samples taken on two separate occasions within the Buccaneer Field show little correlation with suspended sediment samples acquired from Galveston Bay.

Perhaps our main observation with regard to suspended sediments was that their concentration within the water column may vary substantially over periods of a few hours.

Although the intent of this years project was to collect and analyze suspended sediments using sediment traps, we have also conducted an investigation into the dynamics of suspended sediments. This phase of the project involved examination of Earth Resource Technology Satellite (ERTS) photographs of the northern Texas coast. Satellite photographs were examined for surface patterns of suspended sediment. These observations were then correlated with available climatic data (wind speed and direction and precipitation) and discharge and suspended sediment date from United States Geological Survey (USGS) gauging stations on the Sabine, Trinity and Brazos Rivers.

Several general trends are evident:

1) Maximum river discharge generally occurs from March to June. Maximum suspended sediment discharges occur in May.
2) Winds progress from predominantly "northers" in January to southerlies beginning in February and continuing through the spring and summer months. In September, winds are still predominantly from the south and southeast, however there is a strong northeast to northwest component. From October through December north and northeasterly winds predominate.
3) ERTS photographs and climatologic data indicate that suspended sediments from Galveston Bay are transported into the general area of the Buccaneer Field, generally when winds are from the north-northeast (October through January).
4) These photographs also show distinct sediment plumes moving from south to north through the Buccaneer Field during spring

and summer months. The Brazos River is a likely source of these sediments.

Suspended sediment samples were collected from sediment traps on three occasions (11/12/77, 6/21/78 and 8/11/78). Sample descriptions and analytical data for the sediment trap samples are reported in Table 2 and summarized below.

1) The trapped sediments were composed of varying amounts of organic material and detrital mineral debris (Table 2). The organic remains consist of fish fecal pellets, fish bones and scales, barnacle molts, tissue and shell debris, bryozoans, and algae. Most, if not all, of this organic material was derived either directly or indirectly (i.e. fish fecal pellets and remains) from the structures. The detrital mineral material was mostly very fine silt to clay size particles (see mean grain size in Table 2). The lower traps under platforms contained up to 10% finer quartz sand (3.50). All samples analyzed contained some metal flakes.
2) Sediments collected 11/12/77 showed some distinct stratification where as those collected 6/21/78 and 8/11/78 showed very little stratification and were nearly homogeneous.
3) More sediment (both organic and inorganic) was trapped during the November (11/12/77) sampling period than during either of the other two sampling periods (6/21/78 and 8/11/78).
4) The concentration of mineral detritus decreases from the bottom trap to the top trap on all structures during all three sampling periods (see % detrital mineral content, Table 2). Also, there was a greater abundance of mineral

detritus in samples from the production platforms relative to samples from the satellite structures.

The following preliminary conclusions can be made based on the information presented above.

1) The upward (bottom trap to top trap) decrease of mineral detritus in trapped sediments, the presence of 3.50 sands in the lower traps, and the greater abundance of mineral debris in the platform traps as opposed to the satellite traps suggest that resuspension of bottom deposits was the primary source of these sediments.
2) Based on the total amount of sediment collected during a given sampling period, there was a greater concentration of both organic and inorganic material throughout the water column during November than at any other time of the year.
3) Most of the organic material collected in sediment traps is very large and will be deposited in close proximity to the structures. Mineral debris, on the other hand, will not likely come to rest within 175 feet of structures, except for sands which comprise <10% of the terrigeneous sediment. Hence, contaminants associated with organic material will be deposited near structures. However, decomposition will remove most of this material, as evidenced by low organic content of sediments in the area, so that these contaminants will likely be remobilized.
4) The presence of metal flakes in all samples analyzed makes the geochemical data on trapped suspended sediments very difficult to interpret.

C. Geophysical Studies

The Buccaneer Project represents an ideal opportunity to use seismic techniques to search for a suspended sediment layer. In this case, the objective was to locate the suspended sediment layer and to see if it may be tracked by seismic profiling.

The seismic technique has been used with success in various applications in the search for interfaces above the sea floor. Examples include a salinite interface, sea life, gas seep and suspended sediment. The theoretical basis of the technique is the combination of acoustic impedance (written $v_1\rho_1/v_2\rho_2$) and operating frequency of the profiling instrument. In this case, the variation in velocity and density seemed to be adequate to create the proper variation. There was some question about the gradual variation of impedance offered by increasing concentrations of suspended sediment. Our past experience with laboratory measurements concerned with this diffused interface indicated that reflections would be expected. These measurements involved two-dimensional seismic modeling by introducing a pulse into one material and looking for a reflection created by a boundary gradually merging the first material with a second. Here, $v_1\rho_1$ became $v_i\rho_i$, with i gradually changing. Experiments allowed that even if the boundaries were diffused, a pulse of sufficiently high frequency would be reflected from it.

The Buccaneer experiment involved modification of the Rice relection profiling instruments to the 3.5 kc frequency required. After this was accomplished and the modification was tested in Rice's test tank, profiling was conducted in the field.

On July 28, two profiles between platforms 288-A and 288-B were made. At that time a suspended sediment layer was observed which appeared as a diffuse interface. The reflection surface varied and sometimes disappeared. The discontinuity was irregular.

Thus, the seismic technique appears to be applicable to mapping suspended sediment layers in an offshore installation, such as the Buccaneer Field. Future application should involve tests with a variable frequency transducer. This would allow the measurement of density as well as the location of the layer itself.

Conclusions

Bottom sediments in the Bucaneer Field area consist of relict calcareous shell hash, silts and clays of the Beaumont Formation, and sands which are dominated by a strong 3.50 fraction. Analyses of piston core samples show considerable uniformity within subsurface muddy sand. In contrast, surficial deposits in the field show considerable variability with regard to texture. Hence, the Buccaneer Field is a highly dynamic and passive sedimentary environment in which relict sediments are presently being redistributed across the seafloor.

The greatest textural and compositional variability occur within approximately 60 meters of production rigs. This is due to continuous scouring and resuspension around structures. It would appear that up to 50 cm of sediment scouring has occurred near structures.

Suspended sediment analyses were conducted on three sets of samples. One set of sediment samples was taken in November and the others in May and June. Initial findings are listed below.

1) Substantial amounts of organic debris are being shed from the structures. This material will likely come to rest on the seafloor near structures where it will be decomposed.
2) Periodic resuspension results in large concentrations of mineral debris within the lower part of the water column. This phenomenon may well be associated with the near-bottom nepheloid layer that has been observed in the field. The presence of sand-sized material within this sediment, which is too coarse to be transported any considerable distance in suspension, indicates that bottom turbulence and resuspension was the process responsible for suspending these sediments.

Data from USGS gauging stations indicate that the maximum terrestrial influx of suspended sediment into the gulf waters of the Texas coast is in May. Yet, any terrestrial influence on the Buccaneer Field was masked by organic material derived from the structures themselves. Before the influx of suspended sediments from outside the field can be assessed, sediment traps will have to be placed within the field away from the direct influence of structures.

Geophysical studies have shown that the suspended sediment layer in the Buccaneer Field is measurable using seismic equipment. These data indicate the Buccaneer Field suspended sediment layer is patchy and irregular both in thickness and in sediment density. These observations support sedimentologic interpretations that the layer is caused by resuspension of bottom sediments from within the Buccaneer Field area.

PART B

GEOCHEMISTRY OF SURFICIAL SEDIMENTS, SUSPENDED SEDIMENTS AND PRODUCED FORMATION WATERS (BRINE)

PART B: GEOCHEMISTRY OF SURFICIAL SEDIMENTS, SUSPENDED SEDIMENTS AND PRODUCED FORMATION WATERS (BRINE)

I. Introduction

In assessing the environmental impact of offshore oil and gas exploration and production, a detailed study of the trace metal composition of surficial sediments and suspended particulate matter (composed of both organic and detrital components) is important because (Wheeler, Schwarzer and Anderson, 1978):

1. The sediments are the ultimate sink of trace metals in the marine environment, either by sorption onto detrital particles or ingestion by organisms and subsequent deposition as feces or shell material.
2. The suspended particulate matter is highly sorptive of trace metals in the water column. Trace metals will be sorbed by the organic fraction as well as the detrital fraction.
3. Filter feeding organisms ingest the suspended particulate matter which may contain concentrations of trace metals in orders of magnitude greater than the concentrations in seawater.

Figure 14 is a simplified flow diagram showing the pathways and cycles of trace metals in the marine environment of an active oil and gas field. Of particular importance is the interaction and cyclic nature of trace metals in suspended sediments, surficial sediments and marine organisms.

Sediment parameters such as grain size distribution, clay mineralogy, organic carbon and carbonate content can profoundly influence the distribution of trace metals in sediments. These parameters must be accurately determined for quantitative interpretation of trace metal data from sediments. The grain size distribution within the <63μ fraction of a sample is probably the most critical parameter because (1) it is the most influential and the most variable due to the changing conditions of turbulence and (2) determination of the <63μ grain size distribution is difficult, and reproducible results may be obtained only with sensitive settling velocity measurements of the particles. This size fraction includes material which occurs in suspension from time to time maximizing its potential to accumulate trace metals.

Scour of sediments around platform piles due to current and oscillatory wave action is a well documented phenomenon (Machemhl and Abad, 1975) and is active in the Buccaneer Field also (see Part A, Results, Bottom Sediments). Structures and pipelines cause unnatural turbulence and eddying in the water column resulting in erratic winnowing of sediments around the structure. Sediments near the structures are probably being constantly redistributed according to varying conditions of current direction, velocity and wave height.

A. Purpose

The objectives of the geochemical study of the Buccaneer Oil/Gas Field were 1) to document the trace metal (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr, and Zn) concentrations in the surficial sediments, suspended sediments, and produced formation waters (brine); 2) to compare the trace metal concentrations in surficial sediments and suspended sediments with those in unaltered areas; 3) to determine if trace metal concentration gradients exist in the surficial sediments around the drilling structures; 4) to determine the concentrations of trace metals down core in the sediments; and 5) to identify the possible sources of those trace metals found to be present in concentrations greater than expected for an unaltered area.

B. Previous Work

The following is a brief review of the general distribution of trace metals in the Buccaneer Field study area taken from Anderson and Schwarzer (1977). Widely spaced samples were taken throughout the study area (approximately 11.5x3.5 km) and at 8 km intervals from the mouth of Galveston Bay to the study area. These samples provide the basis for determining the general distribution and concentrations of trace metals within the area.

Although the Buccaneer Field occupies a relatively small area, it is a characteristically complex and dynamic sedimentary environment. Distinct mappable sedimentary facies were identified using Q-mode cluster analysis of textural and compositional data (see Figure 8). These sedimentary facies can be classified (on a Shepherd (1954) diagram) as silty/clayey sand, sand, silty sand, clayey silt and gravel. Toward the north end of the study area relict Pleistocene sediments outcrop on the flanks of the domal structure which constitutes the oil field. These ancient sediments are closely associated with adjacent Holocene sediments. Recent sedimentary processes involve reworking of Pleistocene sediments by organisms, wave and current action and shrimp trawlers, as well as deposition of modern sediment moving offshore from terrestrial sources.

Within the production field, samples were taken at closely spaced intervals along four radial transects around each of the two production platforms and around one satellite platform. Sediments collected from around the platforms vary considerably in character reflecting winnowing and resedimentation near the structures. Periods of calm seas and low velocity currents may allow sediment accumulation near structures while increased fluid energy will initiate the suspension and removal of fine detritus and the redistribution of even silt or fine sand-sized material. Therefore, the residence time of sediments (particularly the most critical <63μ fraction) in the area of highest exposure to contaminants is extremely difficult to determine which makes the use of sediments as a quantitative indicator of contamination difficult.

These sediments, however, do indicate that the levels of particular trace metals are greater than the concentrations in control populations. Table 3 compares the means and coefficients of variation (standard deviation/mean x 100) for three groups of samples: The Bureau of Land Management (BLM) South Texas Outer Continental Shelf (STOCS) study area (Berryhill et.al.,1976), the Buccaneer field stations, and the Buccaneer platform stations. The BLM-STOCS control samples are generally finer grained and would be expected to show higher natural background concentrations for most elements. Note that concentrations of Ba, Cd, Ni, and Pb in the Buccaneer field and platform stations are generally higher than for the BLM study area. Similarly, concentrations of Ba, Cd, Pb, and Zn are higher around the structures than in samples taken from field stations. Strontium, although highly variable and having its maximum concentration in the Pleistocene sediments, also averages a higher concentration near the platforms than in the field. The data summarized above indicate some degree of contamination* by Ba, Cd, Ni, Pb, Sr and Zn.

II. Methods and Materials

A. Sampling Procedure

1. Surficial Sediments

Small sediment cores were taken around platform 288-A and a satellite platform (288-3) by divers using 3.5 cm diameter polyethylene tubes and refrigerated until used. The cores were extruded, split longitudinally, and described before sampling. The top and bottom 1 to 2 cm of each core were sampled, placed in porcelain evaporating dishes and dried at 40^o-60^o C for 24 hours. The dried sample was then homogenized with an agate mortar and pestle.

Longer piston cores (up to 1.5m) were obtained at eight stations within the field for subsurface analysis. These cores were treated in the same manner as the smaller cores discussed above except that they were sampled at a number of intervals along their length.

2. Suspended Sediments

Suspended sediments were collected using PVC plastic sediment traps as described in Part A of this report. The first set of traps were placed under platform 288-A at 4.5, 12.0 and 18.5 meters water depth. A second set of traps have been placed under platform 296-B and a satellite structure at approximately 4.5, 12.0, and 18.5 meters water depth.

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* For the purpose of this discussion, the term "contaminants" refers to concentrations of trace elements in the sediment sample (either suspended or bottom) which are significantly high with respect to corresponding data from a suitable control area.

3. Produced Water (Brine)

Samples of the produced formation water were collected from both platform 288-A and 296-B. The brine samples were collected in precleaned 500 ml polyethylene containers and refrigerated. Samples were acidified with 20 ml of concentrated HNO_3 as soon as possible after collection. Temperature and salinity of the brine are recorded on site.

B. Sample Preparation and Analytical Methods

1. Sample Preparation

a. Surficial and Suspended Sediments

Two grains of dried, homogenized sample are treated with 10 ml of 50% H_2O_2 and 20 ml of 50% HNO_3 and then heated to near boiling for one to two hours in a reflux system. The sample is then centrifuged, the supernate poured off, diluted to 50 ml and stored in a refrigerator. The sample is then ready for analysis. For some suspended sediment samples that appeared to be composed mostly of biogenic material, the samples were prepared as biologic samples. Sample preparation of biologic samples is in Part C of this report.

b. Produced Formation Water (Brine)

After the sample has been collected and acidified it is ready for analysis.

2. Analytical Methods

All elements (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr and Zn) were determined using a Perkin-Elmer Model 360 atomic adsorption spectrophotometer (AAS) equipped with a deuterium arc background correction system (Perkin-Elmer Corp, 1973, and Slavin, 1968). Single element hollow cathode lamps and an air-acetylene flame were used for all elements except Ba and Hg. Ba analysis was carried out with a nitrous oxide-acetylene flame and Hg was analyzed by flameless atomic adsorption using A Perkin-Elemr Mercury Analysis System (Hatch and Ott, 1968).

The procedure for Hg analysis was as follows (Goldberg, p. 171-179, 1976):

1. 5 ml of sample solution is pipetted into a graduated cylinder, sufficient 1 N sulfuric acid is added to bring the total volume to 20 ml.
2. Sufficient deionized distilled water is added to the above solution to bring the total volume to 100 ml and the solution is then transferred to a 300 ml BOD bottle.
3. 3 ml of reductant solution* is then added and the BOD bottle is connected to the aeration system of the Hg analyzer. The bottle is gently swirled by hand for 1 minute, then the air pump is started.
4. The absorbance of a sample is measured against that of Hg standards of known concentration.

The mercury in the sample solution is reduced to metallic mercury by the reducing agent. An aerator is placed in the sample solution and a circulating pump moves the air (trapped in the system) through the solution, evaporating the mercury and carrying the vapor through the absorption cell. Mercury vapor in the atomic form absorbs the 253.7 nm radiation emitted from the light source. The change in energy is then detected and read out in the usual way on the atomic absorption spectrophotometer.

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* Reducing Agent: Dissolve 100 ml of concentrated sulfuric acid, 5 grams of sodium chloride, 5.3 grams of hydroxylamine hydrochloride, and 20 grams of stannous chloride in sufficient deionized distilled water to make 1 liter of solution.

C. Quality Control and Statistical Design

1. Quality Control

All solvents and reagents were analyzed to determine the levels of possible contaminants. Reagent blanks were employed following the same experimental techniques as used in sample analysis, and any gross contamination was recognized and eliminated before a sample was processed. All water utilized was deionized and distilled. All acids used in digestions were of such quality that the reagent blanks contain insignificant amounts of the trace metals analyzed, or of interfering elements (see Table 4). All laboratory ware was thoroughly acid washed, rinsed with distilled water and dried in inverted position on a non-contaminating surface.

A number of samples have to be analyzed twice and any of these could be analyzed by another laboratory to compare with our results. The results of the replicated samples are discussed below.

2. Statistical Design

Analytical error was estimated by analyzing a given sample solution a number of times for the same element. Table 5 gives the estimated analytical error for each of the elements determined in this study. The analytical error is a measure of the reproducibility of the analytical method employed.

Sampling error was estimated by analyzing more than one aliquot of the same homogenized sample. The sampling error includes the analytical error plus error caused by sample inhomogeneity or by variation in the sample preparation procedure. Table 6a lists the analysis for all the samples that have been replicated and Table 6b gives the estimated sampling error of each element based on the average differences between duplicated analysis.

III. RESULTS AND DISCUSSON

A. Sediment Cores Collected Within 180 meters of Production Platform 288-A and Satellite Structure S (288-3)

Figure 15 gives the locations of the short sediment cores collected by divers along E-W transects from platform 288-A and satellite structure 288-3. The trace metal geochemistry of the top 1-2 cm of each of these cores is reported in Table 7 and summarized in Table 6. The geographic distribution of each of the twelve elements analyzed in this study is shown in figures 16a through 16l.

An examination of figures 16a through 16l and summary Table 8 reveals some very interesting information relative to 1) increased concentration of trace metal in the surficial sediments, 2) background values of trace metals before anthropogenic contributions and 3) evidence of scour and redistribution of trace metals around structures.

A comparison (see Table 8) of the concentration of trace metals in the surficial sediments (top of cores "A" and "S") with the concentration in the subsurface sediments (bottom of cores "A" and "S") indicates that the surficial sediments contain significantly higher concentrations of Ba, Pb, Sr, and Zn. Mercury also seems to be somewhat enriched in surficial sediments as compared to subsurface sediments. Comparing the surficial sediments (top of cores "A" and "S") with the average trace metal concentrations of surficial sediments from BLM's South Texas Outer Continental Shelf Study (see Table 8) shows the surficial sediments within 180m of the two structures contain significantly higher concentrations of Ba, Pb, and Zn (Sr and Hg were not determined in the BLM study).

When one compares (see Table 8) the average trace metal concentrations of the subsurface sediments (bottom of cores "A" and "S") with the average concentrations in surficial sediments of BLM's study,it is seen that none of the trace metals in the subsurface sediments are present in significantly higher concentrations than those being deposited today on the South Texas Outer Continental Shelf. Thus, the trace metal concentrations of subsurface sediments collected at depths of 12-20 cm are probably representative of background values before anthropogenic contributions. The fact that BLM's surficial sediments contain higher concentrations of Ba, Cr, Fe, Mn, and Zn than the Buccaneer Field subsurface sediments is probably due to the fact that BLM's samples have a finer grain size on the average (i.e. a higher mud content). This is consistent with the fact that they were deposited further offshore in a lower energy environment.

The surficial sediments within 180 m of production platform 288-A (top of cores "A", Table 8) contain greater concentrations of Ba, Pb, Sr, and Zn than do the surficial sediments within 180 m of the satellite structure 288-3 (top of cores "S", Table 8). This is consistent with the facts that 1)production platform 288-A is a much larger structure than the satellite structures (i.e. much more metal in the water), 2) there is and has been a great deal more activity on the production platform (more holes drilled, more metal debris on the bottom, etc.), and 3) there is a discharge of formation waters on the production platform but not on the satellite structures.

An examination of figure 16a through 16ℓ shows that there is an asymmetry in the distribution of many of the trace metals (Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the surficial sediments along the E-W transects. This asymmetry is expressed as higher concentrations of these trace metals along the western transect relative to the eastern transect. Bottom currents in the Buccaneer Field move from east to west, i.e. the surficial sediments along the western transect lie on the down current side of the structures. The increased turbulence created by the structures themselves causes material to remain suspended or to be resuspended and deposited on the down current side of the structures (i.e. the western side). This process is evident up to a distance of 48-90 meters along the western transect and is more pronounced around the large structure (platform 288-A). The distribution of Cr shown in figure 16d is a particularly good example.

One of the primary causes for the high trace metal concentrations near the structures is the fact that the structures are being corroded both above and below water. Pieces of corroded metal are constantly being removed from the structures and accumulating in the surficial sediments. Many of the pieces are very small and can be transported some distance from the structures by currents creating the asymmetric distribution of trace metals discussed above. Very small corroded metal flakes have been identified in many of the surficial sediment samples collected near the structures and in all the trapped suspended sediments collected beneath structures. It would be impossible to identify and separate all the corroded metal debris from the surficial sediments or suspended sediments before analysis for trace metals and no attempt was made to do so in this study.

The Pleistocene Beaumont Formation which is exposed in the eastern portion of the study area (see Figure 8) and covered by 1½ meters or more of recent sediments in the western portion of the study area is exposed or very near the surface close to the structures due to scouring (see Figure 13). Samples identified as Beaumont Formation on the basis of this distinct fine grain size (see Figure 9) are SW1B, SW2B, AOB, AE1B, AW1B, and AW3B. The average trace metal composition of the Beaumont Formation, based on these six samples is given in Table 8. It is seen that the Beaumont has a distinct trace metal geochemistry as compared to the overlying muddy sands which cover most of the study area. The average composition of these overlying muddy sands is given in Table 8 (bottom of cores "A" and "S").

B. Piston Cores

Figure 5 gives the location of the piston cores that were collected in the study area. The trace metal geochemistry of the top 2-3 cm of sediment and at selected depths down core is presented in Table 9a and is summarized in Table 9b. Piston Cores #2, #3, #4, #5, and #6 were collected in the western portion of the study area where the surficial sediments are a muddy sand (see Figure 8) and did not pierce the Beaumont Formation (deepest penetration was 150 cm in core #PC2). On the other hand, cores #12 and #14 were taken in the eastern part of the study area where the Beaumont Formation outcrops (see Figure 8). The trace metal geochemistry of these cores is summarized in Table 9b which shows the following:

1) The subsurface sediments of cores #2, #3, #4, #5 and #6 appear to contain background levels of trace metals (see Anal. #1) when compared to Table 8 (Anal. #2).

2) The average trace metal concentrations in the surficial sediments of cores #2, #3, #4, #5, and #6 (Anal. #2) does not differ significantly from background represented in Anal. #1.

3) The average trace metal concentrations of the subsurface sediments (Beaumont Formation) in cores #12 and #14 are given in Anal. #3; it differs little from the average Beaumont trace metal analysis in Table 8 (Anal. #8) taken from cores near platform 288-A and the satellite structure (288-3). The overall average trace metal composition of the Beaumont Formation is also presented in Table 6 (Anal. #10).

C. Suspended Sediments

The trace metal geochemistry of suspended sediments collected in sediment traps under platforms 288-A, 296-B, and satellite structure 288-3 at water depths of approximately 4.5, 12.0 and 18.5 meters is reported in Table 10a. The analyzed material represents suspended sediment (both organic and inorganic) trapped during 11/12/77, 6/21/78 and 8/11/78. Suspended sediments collected during 11/12/77 were collected under platform 288-A. During the winter months of "77"-"78" the sediment traps were destroyed by severe weather conditions and no suspended sediment was recovered. New, more durable traps were designed (see Figure 2) and placed below both platform 296-B and a satellite structure (288-3). Samples were collected during 6/21/78 and again during 8/11/78 from both platform 296-B and the satellite structure (288-3). Descriptions of all samples are presented in Table 2 and the trace metal geochemistry is presented in Table 10a. Table 10b presents the trace metal data from pumped suspended sediment samples collected during the first year of the study for comparison (Anderson and Schwarzer, 1977).

A major problem in evaluating the analyses of the trapped suspended sediments is the presence of very small pieces of corroded metal from the structure. For example, the very high concentrations of Pb, Cr, and Zn in the sample from the bottom of the top trap (Platform 288-A, Table 10a) are most likely due to metal debris. In order to properly understand the role of suspended sediments in the Buccaneer Field, an open water sampling station some distance from any structure is needed.

The trapped suspended sediments have higher average concentrations of Cr, Cu, Ni and Zn than the surficial sediments near the structures (see Table 8, Anal. #1). Within 48-90 meters of the structures these elements are asymmetrically distributed in the surficial sediments, i.e. they show the effects of resuspension and distribution in a down current western direction (see Figures 16d, 16e, 16i, and 16ℓ).

D. Produced Formation Waters (Brine)

The trace metal geochemistry of the produced formation waters is reported in Table 11 for a number of samples from both platforms 288-A and 296-B. As can be seen from the data, the produced formation waters are very low in most trace elements except Ba, Fe, and Sr. Considering the average Fe concentration in surficial sediments (½ to 2%) the Fe contribution from the brine discharge is insignificant. On the other hand the Sr and Ba concentrations may be very significant and are discussed in greater detail in section E below. It also should be noted that the brine from each platform is quite constant in compostion and distinctly different from each other (see average analysis on Table 11).

E. Sources of Trace Metal Contamination in the Buccaneer Oil/Gas Field

It has been demonstrated by the data presented in Table 8 and 9 and the discussion in Section II A and B that the concentrations of Ba, Pb, Sr, and Zn are significantly higher within 180 meters of the drilling structures. These elements can be classified into three categories based on probable source as follows:

1. Contamination related to drilling operations: Ba -
   It is very probable that the source of most of the Ba in the surficial sediments near the structures is related to the fact that barite ($BaSO_4$) is widely used in drilling muds. The presence of a well crystallized expandable clay mineral (montmorillonite) is also indicative of the presence of drilling muds in surficial sediments near the structures (Anderson and Schwarzer, 1977). But there is another possible source of Ba, the produced formation waters

which contain 2-7 ppm Ba.

2. Contamination related to the drilling structures, including sacrificial electrodes, and assorted debris on the seafloor around the structures : Pb and Zn -

   The structures are being corroded by the marine environment and the material incorporated into the surrounding sediments. Very small, corroded metal particles have been identified in many of the surficial sediment samples and in the trapped suspended sediments. Zn and Pb are normally present in trace amounts in many alloys used in oil field structures. It has also been reported that Zn sacrificial electrodes are presently being used on the structures. Pb may be coming from these sources or may be only casually associated with the structures. Sport fishermen are attracted to offshore structures and the combustion of leaded gasolines has been cited (Hesse and Evans, 1972) as a major source of lead contamination in aquatic environments.

3. Contamination related to the production of formation waters: Sr and (Ba) -

   The produced formation waters are discharged directly into the seawater at each production platform (platform 288-A was closed down 11/13/77 and is no longer discharging formation waters). The water discharged from platform 288-A averaged 48.0 ppm Sr and 5.0 ppm Ba and from platform 296-B averaged 33.5 ppm Sr and 3.5 ppm Ba. The other elements analyzed in this study (Cd,Co,Cr,Cu,Fe,Hg,Mn,Ni,Pb, and Zn) are not present in significant amounts. Both Sr and Ba can be incorporated into the calcium carbonate shells of organisms and hence into surficial sediments and suspended sediments. The aragonite polymorph of calcium carbonate can incorporate more Ba and Sr into its lattice than calcite. Therefore, organisms that secrete aragonite or mixed aragonite - calcite shells, such as most pelecypods and gastropods, will have higher concentrations of both Ba and Sr in their shells (see Milliman, 1974, Tables 32 and 33).

It should be noted here that the first year's study indicated that Cd and Ni were also present in significantly greater amounts when compared to BLM's South Texas Outer Continental Shelf Study (see Table 1). It now seems that the deuterium arc background corrector was not furntioning properly during the first year of the study. This resulted in higher Cd and Ni values because of matrix interferences. Table 6 (Anal. #1) gives the average for surficial sediments collected within 180 meters of platform 288-A and satellite structure S (288-3); the Cd and Ni concentrations are about the same as found in the BLM average (Anal. #7, Table 6). The first year's analyses (Anderson and Schwarzer, 1977) are internally consistant but care must be exercised when comparing with the analyses presented in this report.

IV. CONCLUSIONS

The following conclusions can be made concerning the trace metal geochemistry of the Buccaneer Oil/Gas Field.

1) Of the trace metals analyzed in this report (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr, and Zn) only Ba, Pb, Sr, and Zn

appear to be present in concentrations significantly above background. (see Section III, A).

2) The apparent anthropogenic sources of the Ba, Pb, Sr, and Zn are probably a combination of drilling muds, produced formation waters, and corrosion of the drilling structures. Another possible source for Pb is the combustion of leaded gasoline (see Section III,E).

3) Background concentrations of the trace metals before anthropogenic additions were estimated by two approaches, 1) analysis of surficial sediments in an undeveloped, but similar area (BLM's South Texas Outer Continental Shelf Study) and 2) analysis of subsurface sediments in the Buccaneer Field Study Area that were deposited before development. Both approaches yield very similar results (see Section II, A).

4) Suspended sediments are an important mechanism of transport for trace metals. This is particularly true in the environment of offshore structures which increase the turbulence in the water columns and cause fine particle matter to be constantly resuspended (see Section III, C).

5) From a trace metal standpoint, the Buccaneer Oil/Gas Field appears to have a very small effect on its surrounding environment. It is only within 90-180 meters of the structures that specific trace metals are significantly higher than background.

PART C

TRACE METAL CONTENT OF MARINE ORGANISMS

PART C: TRACE METAL CONTENT OF MARINE ORGANISMS

I. Introduction

Figure 14 is a simplified flow diagram showing the pathways of trace metals in the marine environment of an active oil and gas field. Of particular importance to the discussion of trace metals in marine organisms is the lower part of the diagram labeled "sinks". This part of the diagram illustrates the cyclic nature of trace metals in suspended sediments, surficial sediments and marine organisms. If the suspended sediments and/or sediments become contaminated with trace metals then the filter feeders, infauna and predators will show an increase in their content of trace metals. However, organisms will accumulate trace metals to varying degrees and different organisms will accumulate different trace metals. It is also observed that different tissue samples of the same organisms will accumulate trace metals to different degrees.

It should be pointed out that in the 2.3.2 Work Unit we were contracted to analyze trace metals in marine organisms of the Buccaneer Oil/Gas Field and to tabulate, summarize,and present the results of these analyses in this report. However, we were not contracted to interpret the results in detail because as geologists we feel unqualified to do so. These data are made available so that qualified individuals will formulate their own interpretations concerning the trace metal concentrations in the marine organisms of the Buccaneer Oil/Gas Field.

A. Purpose

The objective of the chemical study of representative marine organisms of the Buccaneer Oil/Gas Field was to determine the trace metal (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr, Zn) composition of 1) the fouling community, 2) the infauna, and 3) the fish that live in close proximity of the drilling structure.

B. Previous Work

Table 12 presents average trace metal levels in the biological specimens analyzed during the first year of this study (Anderson and Schwarzer, 1977). Data from Bureau of Land Management's South Texas Outer Continental Shelf Study is also shown in Table 12 for comparison.

II. Methods and Materials

A. Sampling Procedures

All biological samples were collected by LGL and NMFS. Samples were placed in pre-cleaned containers and frozen as soon as possible.

B. Sample Preparation and Analytical Methods

1. Sample Preparation

The frozen sample is thawed and dissected. The tissue to be analyzed is dried at 40°C and homogenized in an agate mortar and pestle. One gram of dried homogenized sample is treated with 15 ml of a 3:1 HNO_3:$HClO_3$ solution, heated and refluxed for about four hours. The sample is then filtered, diluted to 25 ml, and stored in a refrigerator. The sample is then ready for Atomic Absorption Spectrophotometer analysis.

2. Analytical Methods

All elements (Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sr, Zn) were determined using a Perkin-Elmer Model 360 atomic absorption spectrophotophotometer equipped with a deuterium arc background correction system (Perkin-Elmer Corp., 1973, and Salvin, 1968). Single element hollow cathode lamps and an air-acetylene flame were used for all elements except Ba and Hg. Ba analysis was carried out with a nitrous oxide-acetylene flame and Hg was analyzed by flameless atomic absorption using a Perkin-Elmer Mercury Analysis System (Hatch and Ott, 1968). A detailed description of the procedure for Hg analysis was presented in Section II A.1, Part B of this report.

C. Quality Control and Statistical Design

1. Quality Control

All solvents and reagents were analyzed to determine the levels of possible contaminants. Reagent blanks were employed following the same experiemental techniques as used in sample analysis, and any gross contamination was recognized and eliminated before a sample was processed. All water utilized was deionized and distilled. All acids used in digestions were of such quality that the reagent blanks contain insignificant amounts of the trace metals analyzed, or of interfering element (see Table 4). All laboratory ware was thoroughly acid washed, rinsed with distilled water and dried in inverted position on a non-contaminating surface.

A number of samples have been analyzed twice and any of these could by analyzed by another laboratory to compare with our results. The results of the replicated samples are discussed below.

2. Statistical Design

Analytical error was estimated by analyzing a given sample solution a number of times for the same element. Table 13 gives the estimated analytical error for each of the elements determined in this study. The analytical error is a measure of the reproducibility of the analytical method employed.

Sampling error was estimated by analyzing more than one aliquot of the same homogenized sample. The sampling error includes the analytical error plus error caused by sample inhomogeneity or by variation in the sample preparation procedure. Table 14a lists the analysis for all the samples that have been replicated and Table 14b gives the estimated sampling error of each element based on the average differences between duplicated analysis.

III. Results and Discussion

A. Results

The organisms analyzed in this study were as follows:

1) Fish - The fish species analyzed were spadefish, grey trigger fish, red snapper, sheepshead, soapfish, pinfish, tomtate, blackedge moray, yellow chub, bermuda chub, crested blenny, rough scad, and little tunny. The majority of the samples were from the first five species listed, and the tissue analyzed was either back, belly, or whole fish. Individual analyses are reported in Table 15 and summarized according to species in Table 19.

2) Fish Livers - The fish livers analyzed were from spadefish, red snapper, sheepshead, blackedge moray, and little tunny. The majority of the samples were from the first three species listed. Individual analyses are reported in Table 16 and summarized according to species in Table 19.

3) Barnacles - The barnacles analyzed were collected from platforms A and B and control stations B and F. Specimens were taken at the surface and at 18m depth and in areas affected or not affected by brine discharge. Individual analysis are reported in Table 17 and summarized in Table 19.

4) Benthos - The benthonic organisms analyzed were the horse conch, Atlantic winged oyster, banded tulip shell, spring murex, yellow and brown soft corals, hydroid, arrow crab, octopus, and hermit crab. The majority of the samples were the first 7 species listed. The horse conch specimens were dissected and the pedicle, midsection, muscle, and liver were analyzed separately. Individual analyses are reported in Table 18 and summarized according to species (and tissue type for the horse conch) in Table 19.

B. Discussion

The following discussion is based on the fish tissue analysis (Table 15), the liver analysis (Table 16), and the summary of the data (Table 19). In general, fish livers tend to concentrate Cd (particularly in spade fish), Co, Cu, Fe, Mn, and Zn relative to fish flesh (Table 19). Gray triggerfish and sheepshead are grazers on the fouling community, particularly barnacles; Table 19 shows that on the average they contain higher concentrations of Zn and to a much less extent Fe than do the other fish analyzed. Sheepshead liver is also much higher in Zn. These observations can be related to the fact that barnacles contain high concentrations of Zn and Fe (Table 19). On the other hand, spadefish and red snapper do not contain the high concentrations of Zn and Fe.

On the average, whole barnacles contain more Ba, Cd, Co, Cu, Fe, Mn, Ni, Pb, Sr, and Zn than does fish flesh. There does not seem to be any large differences between the average trace metal content of barnacles collected in areas affected by brine discharge verses those not affected by brine discharge (Table 19); nor, does there seem to be significant differences between samples collected at the surface versus 18m depth (Table 19).

The concentrations of trace metals in benthonic organisms (Table 19) varies widely between different organisms (eg. Banded tulip shell vs. Spiny murex) and between different parts of a given organism (eg. Horse conch pedicle vs. liver).

IV. Conclusions

It is obvious that different organisms have the ability to concentrate trace metals to various levels, some much higher than the concentrations in the surrounding environment (surficial sediments and suspended sediments). Thus, the interaction and cyclic nature of trace metals in suspended particulate matter, surficial sediments and marine organisms as depicted in Figure 14 and the increased turbulence in the vicinity of the structures which suspend and resuspend particulate matter are very important processes in the distribution of trace metals in an active oil and gas field.

LITERATURE CITED

Anderson, J.B., 1968, Ecology of Foraminifera from Mississippi Sound and Surrounding Waters: Jour. Alabama Academy Science, V. 39, p. 1-9.

Anderson, J.B., and B. Borekstra, 1977, Thermal Wedging in Lake Macatawa, Michigan: Long-Term Impact of Channelization: Jour. Great Lakes Research, V. 3, p. 159-163.

Anderson, J.B., and R.R. Schwarzer, 1977, Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico - Sedimentology and Geochemistry: Southeast Fisheries Center, Galveston, Texas, p. 89-164.

Berryhill, H.L., ed., 1975, Environmental Assessment of the South Texas Outer Continental Shelf: Geologic Investigations, Bureau of Land Management.

DiSalvo, L.H., and H.E. Guard, 1975, Hydrocarbons Associated with Suspended Particulate Matter in San Francisco Bay Waters: NTIS AD-AOIL 342 pp.

Drake, 1971, Suspended Sediment and Thermal Stratification in Santa Barbara Channel: Deep Sea Research, V. 18, p. 763-769.

Folk, R.L., 1968, Petrology of Sedimentary Rocks, Hemphill's, Austin, Texas 170 pp.

Gibbs, R.J., 1974, A Settling Tube System for Sand-Size Analysis: Jour. Sed. Petrology, V. 44, p. 583-588.

Gibbs, R.J., M.D. Matthews, and D.A. Link, 1971, The Relationship between Sphere Size and Settling Velocity: Jour. Sed. Petrology, V. 41, p. 7-18.

Goldberg, E. D., ed., 1976, Strategies for Marine Pollution Monitoring, John Wiley and Sons, New York, 310 p.

Hatch, W.R., and W.L. Ott, 1968, Determination of sub-microgram quantities of mercury by atomic absorption spectrophotometry, Analytical Chemistry, V. 40, 2085-2087.

Hesse, J.L. and E.D. Evans, 1972, Heavy metals in surface waters, sediments and fish in Michigan, Michigan Water Resources Commission Bureau of Water Management, Dept. Natural Resources, 5-10.

Hunter, R.E., 1973, Distribution and Movement of Suspended Sediment in the Gulf of Mexico off the Texas Coast: In S.C. Freden, E.P. Mercanti and M. A. Becker (eds.) Symposium on Significant Results Obtained from the Earth Resources Technology Satellite - 1, V. 1, Sect. B, NASA SP-327, p. 1341-1348.

Hunter, R.C., 1976, Movement of Turbid Water Masses Along the Texas Coast In: R.S. William and W.D. Carter (eds.) ERTS-1: A New Window on our Planet, USGS Prof. Paper 929, p. 334-336.

Jordan, C.E.,Jr., G. E. Fryer, and D. Heymann, 1971, Size Analysis of Silt and Clay by Hydrophotometer: Jour. Sedimentary Petrology, V. 41, p. 489-496.

Krumbein, W.C., and F. J. Pettijohn, 1938, Manual of Sedimentary Petrology, D. Appleton - Century Co., New York, N.Y., 549 pp.

Machemehl, J.L., and G. Abad, 1975, Scour Around Marine Foundations: Proc. Offshore Technology Conf., Houston, Texas, OTS-2312.

Manheim, F.T., J.C. Hathaway, and E. Uchupi, 1972, Suspended Matter in Surface Waters of the Northern Gulf of Mexico: Limnol. and Oceanography, V. 17, p. 17-27.

Meyers, P.A., 1976, Association of Hydrocarbons and Mineral Particles in Saline Solution: Nature, V. 244, p. 23-24.

Meyers, P.A., and J.G. Quinn, 1973, Factors Affecting the Association of Fatty Acids with Mineral Particles in Sea Water: Geochim. Cosmochim, Acta., V. 37, p. 1745-1759.

Middleditch, B.S., 1977, Hydrocarbon Levels and Pathways in the Major Components of a Marine Ecosystem: in Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico 1976-77, Southeast Fisheries Center, NOAA Annual Report to EPA, p. 633-736.

Milliman, J.D., 1974, Marine Carbonates, Springer-Verlag, New York 375 p.

Perkin-Elmer Corporation, Norwalk, Conn., 1973, Analytical Methods for Atomic Absorption Spectrophotometry.

Shideler, G.H., 1978, A Sediment Dispersal Model for the South Texas Continental Shelf, Northwestern Gulf of Mexico: Marine Geology, V. 26, p. 289-313.

Salvin, W., 1968, Atomic Absorption Spectroscopy, Wiley Interscience.

Van Andel, T.H., and D.M. Poole, 1960, Sources of Recent Sediments in the Northern Gulf of Mexico: Jour. Sed. Petrology, V. 30, p. 91-122.

Wheeler, R.B., 1977, The Fate of Petroleum in the Marine Environment: Exxon Production Research Company In House Report, 71 pp.

Wheeler, R.B., R.R. Schwarzer, and J.B. Anderson, 1978, Assessment of Environmental Impact of Offshore Production in the Buccaneer Oil Field: Sedimentologic and Geochemical Results: Proc. Offshore Technology Conf., Houston, Texas, OTC-3082, p. 285-290.

TABLE 1 - Size Analysis Data

For station locations see figure 5 for asteriated numerical samples, figure 6 for non-asteriated samples, figure 7 for samples designated alphabetically AE, AW, SE and SW and figure 5 for piston core locations which are designated by the letter P.

Sample Number	% Gravel	% Sand	% Mud	Mean Grain Size	Standard Deviation	Skewness	Kurtosis
2	0.0	68.58	31.42	4.718	2.035	0.739	0.546
3	0.0	55.00	45.00	4.809	2.449	0.513	0.706
4	0.0	57.14	42.86	4.731	2.662	0.308	0.615
5	5.98	78.03	15.99	3.225	2.280	0.045	1.155
6	0.0	42.39	57.61	5.803	2.117	0.422	0.512
9	0.0	68.76	31.24	4.081	2.501	0.381	1.516
10	0.0	61.37	38.63	4.853	2.055	0.682	0.585
11	0.0	53.60	46.40	5.291	2.000	0.739	0.512
13	0.0	47.84	52.16	5.391	2.348	- 0.191	0.501
15	0.0	55.50	44.50	5.121	2.001	0.731	0.487
17	0.0	72.36	27.64	4.251	2.103	0.592	0.673
21	0.0	69.26	30.74	4.203	2.467	0.381	1.011
32	0.0	73.87	26.13	4.224	2.019	0.752	0.956
33	0.0	71.88	28.12	4.137	2.211	0.604	0.851
34	10.91	75.46	13.63	3.383	2.268	- 0.263	2.186
35	0.0	71.13	28.87	4.339	1.949	0.752	0.956
36	0.0	86.94	13.06	3.516	1.563	0.318	4.508
37	0.0	83.84	16.16	3.690	1.761	0.578	4.508
38	0.0	71.47	28.53	3.798	2.670	0.337	0.712
*40	0.0	58.78	41.22	4.882	2.286	0.764	0.501
42	0.0	87.48	12.52	3.497	1.570	0.357	4.303
43	0.0	87.03	12.97	2.818	2.098	- 0.027	1.756
44	0.0	63.12	36.88	4.577	2.075	0.752	0.538
45	0.0	80.96	19.04	2.678	2.494	0.492	1.270
46	0.0	68.92	31.08	4.309	2.241	0.604	0.692
48	0.0	80.98	19.02	3.593	2.171	0.506	4.508
49	0.0	79.15	20.85	3.778	1.887	0.627	5.123
50	0.0	90.80	9.20	3.192	1.375	0.173	4.508
51	0.0	92.07	7.93	3.066	1.468	0.370	4.713
*63	0.0	75.96	24.04	4.122	2.007	0.764	3.005
*67	0.0	55.92	44.08	4.981	2.395	0.736	0.524

TABLE 1, continued.

Sample Number	% Gravel	% Sand	% Mud	Mean Grain Size	Standard Deviation	Skewness	Kurtosis
*69a	0.0	46.84	53.16	5.549	2.309	-0.317	0.478
*71	0.0	41.49	58.51	5.740	2.277	-0.551	0.506
*73	0.0	80.22	19.78	3.901	1.888	0.753	4.508
*76	0.0	70.82	29.13	4.390	1.989	0.739	0.745
*78	0.0	68.33	31.67	4.520	2.158	0.739	0.512
*82	0.0	70.70	29.30	4.373	2.217	0.752	0.506
*87	0.0	73.53	26.47	3.735	2.223	0.590	1.321
*101	0.0	60.28	39.72	4.109	1.509	0.675	1.076
*102	0.0	21.27	78.73	6.530	1.942	-0.856	0.820
AO(0-2)	4.36	34.16	61.48	6.039	3.581	-0.580	0.502
AO(10-12)	2.83	00.77	96.40	8.516	1.343	-0.433	0.878
SO(0-2)	64.15	9.26	26.59	6.751	2.915	-0.415	0.703
SO(9-11)	0.69	2.75	96.56	8.389	1.489	-0.147	0.995
AE1(0-2)	26.45	47.28	26.27	3.847	3.068	0.310	0.761
AE1(15-17)	2.93	6.13	90.94	7.711	1.841	-0.107	0.931
AE2(0-2)	6.44	67.34	26.22	3.457	2.894	0.253	0.842
AE2(14.5-16.5)	0.85	26.45	72.70	5.818	2.098	0.185	0.922
AE3(0-2)	6.89	75.31	17.80	3.445	2.101	-0.043	2.459
AE3(12-14)	0.92	65.21	33.87	4.716	1.792	0.675	2.459
AE4(0-2)	2.77	78.73	18.50	3.488	1.630	0.292	2.459
AE4(14-16)	0.0	57.02	42.98	3.590	3.580	0.110	0.662
AE5(0-2)	3.79	85.32	10.88	3.533	1.541	0.327	3.005
AE5(10.5-12.5)	1.87	65.97	32.16	4.647	1.954	0.731	1.522
AE6(0-2)	1.15	69.56	29.30	4.268	2.124	0.756	1.383
AE6(12.5-14.5)	1.10	52.75	46.15	5.107	2.192	0.767	0.969
AE7(0-2)	2.84	78.31	18.84	3.697	1.757	0.569	4.918
AE7(18-20)	0.47	55.49	44.04	5.023	1.895	0.737	1.025
AW1(0-2)	5.49	39.68	54.84	5.307	3.105	0.000	0.703
AW1(11-13)	1.77	3.04	95.19	8.448	1.433	-0.278	1.054
AW2(0-2)	21.51	72.64	5.85	1.723	1.883	0.542	3.279
AW2(12-14)	1.21	51.49	47.30	4.487	3.337	0.274	0.607
AW3(0-2)	10.00	25.88	64.12	6.150	3.018	-03.53	0.722
AW3(13.5-15.5)	0.0	0.35	99.65	8.340	1.316	-0.183	0.683

TABLE 1, continued.

Sample Number	% Gravel	% Sand	% Mud	Mean Grain Size	Standard Deviation	Skewness	Kurtosis
AW4(0-2)	0.69	42.2	57.28	5.497	2.474	-0.041	0.966
AW4(19-21)	7.30	65.62	27.08	4.244	1.663	0.510	1.434
AW5(0-3)	33.69	55.28	11.02	2.441	2.602	0.618	1.742
AW5(17.5-19.5)	0.53	49.99	49.48	5.336	2.120	0.721	0.969
AW6(0-2)	5.04	83.28	11.68	2.859	1.971	0.452	3.689
AW6(15-17)	8.46	64.00	27.54	4.252	1.935	0.698	1.581
AW7(0-2)	3.84	72.14	24.02	4.158	1.888	0.692	3.552
AW7(18-20)	0.24	66.49	33.27	4.705	2.002	0.692	1.776
SE1(0-2)	3.10	89.73	7.17	3.063	0.958	-0.200	2.049
SE1(12-14)	0.33	23.43	76.23	6.683	2.381	-0.139	0.615
SE2(0-2)	0.65	68.80	3.054	4.338	1.970	0.615	1.522
SE2(12-14)	0.79	40.03	59.18	4.934	1.358	0.222	1.230
SE3(0-2)	1.99	78.52	19.49	3.728	1.680	0.618	3.005
SE3(13-15)	0.99	23.99	75.01	5.655	1.813	0.375	1.230
SE4(0-2)	14.85	63.48	21.67	4.220	1.619	0.628	2.049
SE4(6-8)	0.13	55.86	44.01	4.903	2.104	0.760	0.969
SE5(0-2)	1.96	71.09	26.96	4.150	1.875	0.679	1.522
SE5(15-17)	1.22	61.13	37.64	4.686	1.983	0.742	1.332
SE6(0-2)	1.53	70.12	28.35	4.177	1.888	0.673	1.464
SE6(15.5-17.5)	8.07	59.68	32.25	4.565	2.074	0.698	1.383
SE7(0-2)	8.26	59.42	32.33	4.465	2.090	0.756	1.383
SE7(16-18)	0.00	61.32	38.68	4.848	1.859	0.737	1.464
SW1(0-2)	10.18	19.46	70.37	6.259	2.647	-0.171	1.341
SW1(9.5-11.5)	0.31	00.53	99.16	8.528	1.266	-0.540	0.820
SW2(0-1)	2.20	24.13	73.67	7.453	2.766	-0.747	0.615
SW2(8.5-10.5)	0.33	9.26	90.41	8.173	1.853	-0.561	1.230
SW3(0-2)	2.10	66.53	31.38	4.380	1.982	0.709	1.581
SW3(18-20)	0.76	26.13	73.10	6.353	2.281	0.101	0.692
SW4(0-2)	0.23	76.90	22.87	4.196	1.576	0.476	4.303
SW4(15-17)	1.59	64.58	33.82	4.634	1.960	0.709	1.581
SW5(0-2)	2.00	22.03	75.97	6.918	2.277	-0.282	0.651
SW5(7.5-9.5)	1.62	35.24	63.14	5.504	2.045	0.437	1.066
SW6(0-2)	2.10	72.99	24.91	4.161	1.826	0.659	1.885

TABLE 1, continued.

	Sample Number	% Gravel	% Sand	% Mud	Mean Grain Size	Standard Deviation	Skewness	Kurtosis
	SW6(13-15)	2.28	63.70	34.02	4.675	1.967	0.742	1.522
	SW7(0-2)	3.25	71.74	25.01	4.262	1.935	0.698	1.844
	SW7(7.5-9.5)	6.20	65.29	28.51	4.484	1.709	0.698	1.708
P	2(0-4)	0.00	66.21	33.79	3.426	2.729	0.190	0.605
	2(57-60)	0.40	54.46	45.14	4.886	2.014	0.739	0.585
	2(127-130)	0.40	56.67	42.92	4.587	2.068	0.746	0.662
	3(0-3)	0.00	81.18	18.82	3.829	1.407	0.600	4.098
	3(55-58)	0.00	57.65	42.35	4.708	1.789	0.732	0.745
	3(73-76)	0.00	63.29	36.71	4.509	1.818	0.717	0.820
	4(0-4)	2.37	76.20	21.43	3.860	1.750	0.628	4.303
	4(54-57)	0.00	48.44	51.56	5.149	1.971	0.451	0.506
	5(0-3)	0.10	84.29	15.62	3.745	1.382	0.350	4.098
	5(56-59)	0.00	67.47	32.53	4.319	1.787	0.696	1.025
	5(93-96)	0.00	62.15	37.85	4.641	1.805	0.725	0.745
	6(0-3)	0.00	79.15	20.85	4.025	1.527	0.628	4.098
	6(60-63)	0.00	63.42	36.58	4.609	1.562	0.688	1.112
	6(120-123)	0.00	54.89	45.11	4.814	1.781	0.709	0.779
	12(0-2)	12.11	45.92	41.97	4.275	2.216	0.326	0.977
	12(56-61)	0.00	7.21	92.79	7.015	1.358	-0.609	1.557
	12(92-95)	0.00	20.54	79.46	6.473	1.990	-0.764	0.943
	12(126-129)	1.66	31.56	66.78	5.661	1.982	-0.198	0.506
	12(153-156)	10.04	9.32	80.65	6.642	1.544	-0.527	1.171
	14(17-20)	0.00	6.10	93.90	7.273	1.326	-0.635	4.303

TABLE 2 - Trapped Suspended Sediment Data

The sample locations, sample descriptions, organic contents (%), detrital mineral contents (%), and sediment analysis data are presented in this table for trapped suspended sediment samples collected during the periods 9/2/77 to 11/12/77, 2/15/78 to 6/21/78 and 6/21/78 to 8/11/78.

Sample Location and Date of Collection, and analysis number reported in Table 10a	Sample Description	Organic Content (%)	Detrital Mineral Content (%)	Sediment Size Analysis Data Ø-mean grain size SD-standard deviation
Platform 238-A 11/12/77				
top 1 cm. Shallow Depth Trap 1	a light concentration of detrital material in upper portion predominantly organic skeletal material, scales, tissue, algae and bryozoans. Some metal flakes and quartz grains	71	30	* (* indicates insufficient detrital mineral content for sediment size analysis)
3 cm. Shallow Depth Trap 2		73	27	
top 1 cm. Mid Depth Trap 3	organics same as above predominantly skeletal material, tissue, scales, hard parts, very fine detrital material and metal flakes	61	39	Ø - 7.536 SD - 1.593
2 cm. depth in Mid Depth Trap 4	same as above	60	40	Ø - 7.841 SD - 1.515
3 cm. depth in Mid Depth Trap 5	same as above - organics mostly tissue, metal flakes and Fe staining	57	43	*
5.cm depth in Mid Depth Trap 6	same as above	54	46	Ø - 7.962 SD - 1.678

Table 2, continued

Sample Location and Date of Collection		Sample Description	Organic Content (%)	Detrital Mineral Content (%)	Sediment Size Analysis Data Ø-mean grain size SD-standard deviation
8 cm.depth in Mid Depth Trap	7	pteropods, bryozoans algae larger hard parts - some algae and bryozoans	50	50	Ø - 8.897 SD - 1.567
3 cm. depth in Near Bottom Trap	8	fine organic fabric, lack of larger material, some scales and bone - larger detrital component	22	78	Ø - 7.867 SD - 1.697
6 cm. depth in Near Bottom Trap	9		24	76	*
10 cm. depth in Near Bottom Trap	10	large pieces of metal flakes some slightly larger organics, scales and skeletal material, tissue and Fe staining	20	80	Ø - 7.711 SD - 1.725
Platform 296-B 6/21/78					
Shallow Depth Trap Top	11	predominantly organics, skeletal material, tissue ostracods, bryozoans, algae gastropods, some quartz grains, and abundant metal flakes	73	27	*
Bottom	12		69	31	*

Table 2, continued

Sample Location and Date of Collection	Sample Description	Organic Content (%)	Detrital Mineral Content (%)	Sediment Size Analysis Data Ø-mean grain size SD-standard deviation
Mid Depth Trap Top 13	again predominantly organics coated with fine clay material - shell fragments, pteropods, gastropods, algae, some quartz grains	55	45	Ø - 7.813 SD - 1.528
Bottom 14		70	30	*
4 cm. depth in Near Bottom Trap 15	large detrital component, fine silts and clays. Organics consist of skeletal material, shell fragments, scales, gastropods, bryozoans	11	89	Ø - 6.590 SD - 1.779
6 cm. depth in Near Bottom TRap 16		8	92	Ø - 6.500 SD - 1.721
8 cm. depth in Near Bottom Trap 17	same as above with slightly larger organics, bones, etc. and metal flakes	6	94	Ø - 6.369 SD - 1.526
Satellite Platform 288-3 6/21/78				
Shallow Depth Trap Top 18	Predominantly organics same as previously described - skeletal material, gastropods, scales, tissue, some metal flakes	69	31	*
Bottom 19		71	29	*
2 cm depth in Mid Depth Trap 20	organics same, some grains of quartz	54	46	Ø - 8.810 SD - 1.535

Table 2, continued

Sample Location and Date of Collection	Sample Description	Organic Content (%)	Detrital Mineral Content (%)	Sediment Size Analysis Data Ø-mean grain size SD-standard deviation
5 cm. depth in Mid Depth Trap 21	organics same as above, abundant large metal flakes	79	21	*
Near Bottom Trap 22	organics same -skeletal material, tissue, etc., Detrital component, predominantly fine silts and clays	35	65	Ø - 7.005 SD - 1.372
Platform 296-B 8/11/78				
Shallow Depth Trap Top 23	predominantly organic - skeletal fragments, scales, tissue, fecal material, brozoans, some shell fragments	93	7	*
Bottom 24		90	10	*
Mid Depth Trap - Top 25	predominantly organics same as above, Some metal flakes	95	5	*
Bottom 26		92	8	*
Near Bottom Trap 27	Organic component same as above. Detrital component is larger, mostly fine silts and clays, some metal flakes	43	57	Ø - 5.994 SD - 1.930

Table 2, continued

Sample Location and Date of Collection	Sample Description	Organic Content (%)	Detrital Mineral Content (%)	Sediment Size Analysis Data Ø-mean grain size SD-standard deviation
Satellite Structure 288-3 8/11/78				
Shallow Depth Top 28	predominantly organics, tissue material, bryozoans, shell fragments, scales, Some metal flakes.	86	14	*
Bottom 29		80	20	*
Mid Depth Trap Top 30	organics are the same as above with some slightly larger scales and bone material	93	7	*
Bottom 31		90	10	*
Near Bottom Trap 32	a larger detrital component but still predominantly organics same as above	59	41	Ø - 6.172 SD - 1.475

Table 3. Trace Metal Concentration in Surficial Sediments

This table presents for comparison the trace metal concentrations in surficial sediments from the Buccaneer Field Study (field samples and structure samples reported separately) and from BLM's South Texas Outer Continental Shelf Study. All concentrations are in ppm except Fe which is in percent present and V is the coefficient of variation. The "structure samples" were collected at distances of 8m, 24m, 48m, and 180m from both production platforms and one satellite structure. Note that all values have been rounded to the nearest 0.5 ppm and Fe to the nearest 0.01%.

	BLM[1]		Buccaneer[2] Field Stations		Buccaneer[2] Structure Stations	
Element	$\bar{X}$	V	$\bar{X}$	V	$\bar{X}$	V
Ba	101.0	52%	144.0	55%	355.5	50%
Cd	0.5	40%	1.5	32%	1.5	16%
Cu	6.5	25%	5.0	35%	5.5	48%
Cr	22.5	24%	7.0	72%	7.5	48%
Fe	2.19	15%	0.47	34%	0.47	25%
Mn	362.5	25%	165.0	46%	160.5	25%
Ni	17.0	26%	30.5	22%	25.0	15%
Pb	9.0	27%	13.0	47%	18.0	58%
Zn	63.0	18%	40.0	25%	53.0	35%
Sr	these elements not determined in BLM study		77.0	211%	98.5	74%
Co			19.0	17%	20.0	18%

1. Data from BLM Environmental Assessment of the South Texas Outer Continental Shelf, Geologic Investigations, Oct. 25, 1975 to Dec. 1, 1975, Table 17, p. 206.
2. Data from Anderson and Schwarzer (1977).

Table 4. Reagent Blanks.

This table reports the average reagent blanks for each element analyzed and for each of the two digestion procedures, concentrations in ppm.

Element	Sediment Blank 20ml, 50% HNO_3 10ml, 50% H_2O_2 diluted to 50ml	Biological Blank 20ml of 3:1 HNO_3 - $HClO_4$ diluted to 25ml
Ba	0.00	0.00
Cd	0.00	0.00
Co	0.00	0.00
Cr	0.13	0.40
Cu	0.00	0.00
Fe	0.16	0.24
Hg	0.00	0.00
Mn	0.00	0.00
Ni	0.12	0.16
Pb	0.09	0.07
Sr	0.00	0.00
Zn	0.09	0.09

Table 5. Estimated Analytical Error for Sediment Samples

This table reports the estimated analytical error (standard deviation in %) based on duplicate analysis of numerous sample solutions. The analytical error is estimated individually for sediments (this Table) and for biological samples (Table 13). The number in parenthesis is the number of duplicate samples used to estimate the analytical error of that particular element.

Element	Estimated Analytical Error for Sediment Samples	
Ba	9%	(15)
Cd	15%*	(10)
Co	6%	(15)
Cr	13%	(12)
Cu	10%	(15)
Fe	10%	(14)
Hg	20%*	(10)
Mn	5%	(14)
Ni	11%	(18)
Pb	13%	(14)
Sr	5%	(10)
Zn	5%	(17)

* The large analytical errors in Cd and Hg are due to the low concentration of these elements in the samples.

Table 6a. Duplicated Analysis of Sediment Samples

This table presents the analysis of duplicated samples, i.e. two aliquots of the same homogenized sample were prepared and analyzed. Group I samples are from this year's study (Table 5, and Figure 15) and Group II samples are from last year's study (Anderson and Schwarzer, 1977, Table 3 and Figure 4). Fe reported in %, all others in ppm.

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
Group I												
AE4B$_1$	58	0.0	9.5	22.5	6.5	1.52	0.1	210.5	16.5	9.0	10.0	33.0
AE4B$_2$	75	0.0	10.5	20.5	7.5	1.32	<0.1	233.0	12.0	10.0	12.5	39.5
AE7B$_1$	112	0.0	7.5	24.0	5.5	1.10	0.1	197.5	11.5	9.0	11.0	32.5
AE7B$_2$	108	0.0	8.0	17.0	5.5	1.10	0.2	204.0	11.0	9.5	10.0	33.0
SE5T$_1$	264	0.0	5.5	2.5	3.0	.76	0.1	193.0	7.5	10.0	31.0	26.0
SE5T$_2$	268	<0.5	7.0	8.5	3.0	.83	0.1	190.0	7.5	8.0	19.0	39.0
SE5B$_1$	55	0.0	9.5	9.5	6.5	1.27	<0.1	182.0	10.0	9.5	9.0	29.0
SE5B$_2$	50	<0.5	8.0	15.5	5.0	1.02	<0.1	210.5	13.0	6.5	12.0	34.0
SW4B$_1$	24	<0.5	5.0	1.0	2.0	1.18	<0.1	159.5	5.0	5.0	18.5	17.5
SW4B$_2$	28	0.0	7.0	11.5	2.5	.84	0.1	152.5	5.5	5.5	11.5	16.5
SW7T$_1$	321	0.0	5.0	3.5	4.5	.89	0.1	225.0	8.0	6.5	23.0	27.5
SW7T$_2$	201	<0.5	8.0	5.5	3.5	.74	0.1	215.0	6.0	5.5	20.5	33.5
Group II												
F$_1$	41	1.0	6.5	5.0	2.5	.61	0.1	160.5	7.0	5.5	22.5	23.0
F$_2$	41	1.0	6.5	1.5	2.5	.52	0.1	162.0	6.0	5.0	45.0	20.5
69$_1$	84	<0.5	7.5	20.0	4.5	1.13	<0.1	189.5	12.5	7.5	9.0	38.5
69$_2$	70	<0.5	7.5	26.0	4.0	1.25	0.1	157.0	11.0	8.0	27.0	34.0

Table 6a. continued

Sample Numbers	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
78_1	56	1.0	8.0	11.0	4.0	1.00	0.1	145.5	9.5	6.5	10.0	25.5
78_2	39	1.5	5.0	8.0	3.5	1.03	0.1	140.0	10.5	7.0	8.5	25.0
87_1	109	<0.5	9.0	11.5	5.5	1.01	0.1	201.5	12.0	10.0	51.0	32.5
87_2	182	<0.5	5.0	14.0	3.0	.89	0.1	147.0	13.5	7.0	21.0	27.5

Table 6b. Estimated Sampling Error For Sediment Samples

This table presents the estimated sampling error (which includes the analytical error reported in Table 5) based on the duplicated analysis given in Table 6a.

Element	Estimated Sampling Error
Ba	15%
Cd	~25%[1]
Co	17%
Cr	30%
Cu	14%
Fe	10%
Hg	~25%[1]
Mn	6%
Ni	12%
Pb	15%
Sr	31%[2]
Zn	11%

1. The sampling error in Cd and Hg is estimated. An accurate sampling error cannot be calculated because most of the concentrations are at or below the detection limit.

2. The large sampling error in Sr is due to the highly variable content of shell material within samples.

Table 7. Geochemistry of Diver Obtained Sediment Cores collected within 180 m of Platform 288-A and Satellite Structure S (288-3).

Station locations are given in Figure 15. "T" designates the top 1-2 cm of the core and "B" designates the bottom 1-2 cm of the core. The exact depths at which the bottom (B) samples were taken for each core is given in Part A, Table 1 of this report. Fe concentrations are in %, all others in ppm.

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
AOT	367	<0.5	12.5	27.5	25.0		0.6	293.5	30.0	166.0	117.0	307.5
AOB	47	<0.5	13.5	40.0	13.5		0.3	207.0	32.0	19.0	5.0	91.5
AE1T	308	0.0	7.0	15.0	9.0	.98	0.3	171.5	13.0	23.5	235.0	149.0
AE1B	50	0.0	14.0	35.0	16.0		0.2	200.5	29.5		7.0	68.5
AE2T	142	0.0	7.5	12.0	5.5	1.29	0.8	237.0	11.5	950.0		
AE2B	101	<0.5	10.5	13.5	9.0	1.29	0.2	243.5	12.0	8.5	9.0	32.0
AE3T	396	<0.5	7.5	8.0	3.5	.84	<0.1	167.0	7.0	31.0	25.5	40.0
AE3B	48	0.0	13.0	34.5	19.0	2.27	<0.1	144.5	31.0	16.0	7.5	85.5
AE4T	595	0.0	7.5	6.0	2.0	.67	0.2	192.5	7.0	22.0	31.5	40.5
AE4B	67	0.0	10.0	22.5	7.0	1.42	0.1	222.0	14.5	9.5	11.0	36.0
AE5T	783	0.0	8.0	4.0	3.0	.59	<0.1	162.0	5.0	15.5	119.0	30.5
AE5B	63	0.0	7.0	16.5	5.5	1.06	0.1	187.5	11.5	6.5	11.5	33.0
AE6T	751	0.0	7.5	6.0	3.5	.77	0.1	191.0	8.5	21.0	77.0	31.5
AE6B	45	0.0	8.0	9.5	6.0	1.05	0.1	221.5	10.5	8.0	8.5	30.0
AE7T	114	<0.5	8.0	8.0	3.5	.88	<0.1	209.5	8.0	8.5	18.0	28.5
AE7B	110	0.0	7.5	20.5	5.5	1.10	0.2	200.5	11.0	9.5	10.5	32.5

Table 7 . continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
AW1T	134	1.5	14.5	19.5	25.5		<0.1	275.0	29.5	86.0	98.5	363.5
AW1B	48	0.0	12.0	44.0	21.0	2.13	0.2	155.0	31.0	19.5	5.5	92.5
AW2T	388	<0.5	7.5	28.0	17.0	1.43	0.3	254.5	16.0		477.5	370.5
AW2B	401	7.5	0.0	8.5	18.5	1.19	0.1	197.5	8.0		121.0	320.5
AW3T	310	0.0	11.0	31.5	12.5	1.95	0.1	240.0	22.0	74.0	12.0	281.5
AW3B	53	<0.5	9.5	8.5	4.0	.92	0.0	175.5	11.0	6.0	32.0	25.5
AW4T	108	0.0	12.0	30.5	11.0	1.88	<0.1	247.0	20.5	26.0	10.0	59.0
AW4B	47	0.0	12.0	2.0	14.0	1.88	0.0	162.5	22.5	11.5	5.0	52.5
AW5T	332	0.0	8.0	15.5	9.0	1.07	0.3	231.0	11.5		328.0	337.5
AW5B	<10	0.0	1.5	0.0	0.5		<0.1	0.0	0.0	0.0	22.0	0.0
AW6T	241	0.0	3.5	1.0	2.0	.41	0.3	120.5	4.0	56.0	55.5	50.5
AW6B	160	<0.5	8.0	12.5	4.0	.96	<0.1	171.0	9.5	7.5	15.0	28.5
AW7T	424	0.0		9.0	6.5	.85	<0.1	204.5	7.5	20.0	43.5	64.5
AW7B	41	0.0	7.5	10.5	5.5	1.05	<0.1	187.0	10.5	7.5	8.0	27.5
SOT	482	1.5	12.5	18.0	7.0	1.64	0.2	187.0	18.5	53.0		372.5
SOB	<10	0.0	1.5	0.0	0.5		0.0	54.0	0.0	0.0	12.0	3.0
SE1T	270	1.0	8.5	3.0	3.5	.73	0.2	187.0	7.0	15.0	51.0	25.5
SE1B	45	<0.5	12.0	20.5	10.5	1.69	<0.1	189.5	20.5	9.5	4.5	50.0
SE2T	141	0.0	6.5	6.0	4.0	.91	0.1	247.5	8.0	6.5	40.5	26.5
SE2B	37	0.0	7.5	42.0	6.5	1.36	<0.1	158.5	14.0	10.0	8.0	31.0
SE3T	235	0.0	7.0	7.0	3.5	.88	0.1	212.0	8.0	6.0	17.0	27.0
SE3B	49	<0.5	8.5	10.0	5.5	1.11	<0.1	207.0	12.5	4.5	4.0	27.5
SE4T	170	<0.5	5.5	3.0	4.0	.77	<0.1	150.0	7.0	5.5	27.5	22.5
SE4B	149	0.0	8.5	12.5	4.0	1.02	<0.1	218.0	10.0	7.0	13.0	32.0
SE5T	266	<0.5	6.5	6.5	3.0	0.80	0.1	191.5	7.5	9.0	25.0	32.5
SE5B	53	<0.5	9.0	12.5	6.0	1.15	<0.1	196.5	11.5	8.0	10.5	31.5

Table 7. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
SE6T	279	0.0	7.0	3.5	2.5	.63	0.2	183.5	6.0	5.5	47.5	34.0
SE6B	48	0.0	8.0	15.0	5.0	1.14	<0.1	188.0	11.0	8.0	9.5	30.0
SE7T	1,379	0.0	8.5	4.0	4.0	.84	0.1	257.5	8.0	14.0	77.5	27.5
SE7B	37	<0.5	7.5	11.0	5.5	1.09	<0.1	164.0	10.0	3.5	8.0	28.5
SW1T	103	0.0	10.5	32.5	8.5	2.19	0.1	223.0	26.5	20.0	35.5	92.5
SW1B	15	1.0	19.5	7.0	25.3	.89	0.0	108.5	31.5	14.5	3.5	48.0
SW2T	128	0.0	14.0	24.5	11.0	1.57	0.2	369.0	19.5		37.5	51.0
SW2B	38	1.0	13.5	16.5	16.0	2.44	0.2	220.5	33.0	21.0		68.5
SW3T	206	<0.5	10.0	16.5	5.0	1.20	0.1	219.5	11.5	18.5	11.0	42.5
SW3B	72	0.0	10.5	23.5	10.5	2.61	0.1	256.0	30.0	12.5	5.5	43.5
SW4T	221	<0.5	7.5	3.5	4.0	1.18	0.1	193.5	8.0	13.0	63.5	25.5
SW4B	26	<0.5	6.0	6.5	2.5	1.01	0.1	156.0	5.5	5.5	15.0	17.0
SW5T	194		8.0	12.5	6.5	1.20	0.1	231.5	13.0	10.0	38.5	39.0
SW5B	54	0.0	0.0	5.0	7.0	.92	<0.1	231.0	9.5	8.5	11.0	23.5
SW6T	695	<0.5	8.5	9.0	4.5	.96	0.1	205.5	8.5	16.0	37.5	51.0
SW6B	162	0.0	8.5	9.0	4.5	1.05	<0.1	178.5	12.0	8.5	34.5	27.5
SW7T	261	0.0	6.5	4.5	4.0	0.82	0.1	220.0	7.0	6.0	22.0	30.5
SW7B	113	0.0	8.5	16.5	6.0	1.22	<0.1	194.0	12.0	6.0	8.5	33.5

Table 8. Summary of the Trace Metal Geochemistry of Diver Obtained Cores Collected Within 180 M of Platform 288-A and Satellite Structure S (288-3).

This table presents a summary of the trace metal geochemistry of sediment cores presented in Table 7. The cores were collected along E-W transects about platform 288-A and a satellite structure S (288-3). See Figure 15 for locations. The top 1-2 cm and the bottom 1-2 cm of each core was analyzed. Fe concentrations are in %, all others in ppm. The analyses are average values for the following samples:

Anal. #1 - Average analysis of the top of all cores from platform A and satellite S.

Anal. #2 - Average analysis of the bottom of all cores from platform A and satellite S, except those from Beaumont Formation (see Anal. #8).

Anal. #3 - Average analysis of the top of all cores from platform A.

Anal. #4 - Average analysis of the top of all cores from satellite S.

Anal. #5 - Average analysis of the bottom of all cores from platform A except those from the Beaumont Formation (see Anal. #8).

Anal. #6 - Average analysis of the bottom of all cores from satellite structure S except those from the Beaumont Formation (see Anal. #8).

Anal. #7 - Average analysis of the surficial sediments of the BLM South Texas Outer Continental Shelf Study (see table 1).

Anal. #8 - Average analysis of the samples from the Beaumont Formation (SW1B, SW2B, AOB, AE1B, AW1B and AW3B; table 6).

Anal. #9 - Average analysis of the samples from the Beaumont Formation collected by piston cores (subsurface samples from piston cores PC12 and PC 14, Table 9a.

Anal. #10- Average analysis of the Beaumont Formation (weighted average of Anal. #8 and Anal. #9).

Analysis Numbers	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Number of Samples In Average
Anal. #1 (Top of A&S)	342	0.5	8.0	12.0	7.0	0.99	0.2	215.0	12.0	53.5	69.5	97.5	32
Anal. #2 (Bottom of A&S)	81	0.5	8.0	14.0	8.0	1.23	0.1	187.0	12.5	7.5	15.0	42.5	27
Anal. #3 (Top of A)	360	0.5	8.0	15.0	9.0	0.91	0.2	213.0	13.5	100.0	110.0	143.5	15

Table 8. continued

Analysis Numbers	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Number of Samples In Average
Anal. #4 (Top of S)	327	0.5	8.0	9.5	4.5	1.06	0.1	217.0	10.5	12.5	34.0	56.5	17
Anal. #5 (Bottom of A)	97	0.5	8.5	13.0	8.0	1.21	0.1	181.5	13.0	8.0	19.5	57.5	13
Anal. #6 (Bottom of S)	66	<0.5	8.0	14.5	5.5	1.25	0.1	192.0	12.5	7.5	11.0	20.0	14
Average Analysis from BLM Study (see table 1)													
Anal. #7	101	0.5	n.d.	22.5	6.5	2.19	n.d.	362.5	17.0	9.0	n.d.	63.0	
Average Analysis of Beaumont Formation													
Anal. #8	42.0	<0.5	13.5	25.0	16.0	2.06	<0.2	181.5	28.0	16.0	10.5	65.8	6
Anal. #9	48.0	0.0	13.0	19.5	14.5	2.42	<0.2	225.5	11.0	23.5	10.0	49.5	4
Anal. #10	44.5	<0.5	13.5	23.0	15.5	2.20	<0.2	199.0	21.0	19.0	10.5	59.0	10

Table 9a. Trace Metal Geochemistry of Sediments Collected by Piston Cores

Station locations for the piston cores are given in Figure 5. PC followed by a 1 or 2 digit number refers to piston core number and the numbers in parentheses represent the depth (cm) in the core where the sample was taken. The concentration of carbonate and Fe is in %, all others in ppm.

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Carbonate Content
PC2 (0-4)	49	0.0	7.0	6.5	7.0	1.12	0.1	156.0	2.5	10.0	11.0	40.0	4.3
PC2 (57-60)	42	0.0	7.0	13.5	6.5	1.32	<0.1	175.5	6.5	8.0	9.0	35.5	4.0
PC2 (127-130)	42	0.0	6.0	11.0	6.0	1.32	0.1	179.0	5.0	7.0	9.0	36.5	5.5
PC3 (0-3)	48	0.5	5.5	12.0	5.5	0.80	0.2	126.0	0.0	8.5	19.0	31.0	3.0
PC3 (55-58)	39	0.5	5.5	17.5	6.0	1.17	0.2	165.0	5.5	9.5	8.0	34.5	3.7
PC3 (73-76)	40	0.5	5.5	24.5	6.0	1.14	0.1	159.0	3.5	8.5	8.5	32.5	3.7
PC4 (0-4)	67	0.0	6.5	23.5	15.0	0.97	0.1	145.5	6.0	10.5	20.5	50.5	4.3
PC4 (54-57)	41	0.0	7.0	21.0	9.0	1.42	0.2	169.0	10.0	12.0	8.0	57.5	3.7
PC5 (0-3)	31	0.5	5.5	15.0	6.0	0.76	0.2	126.0	2.5	6.5	8.5	35.5	3.2
PC5 (56-59)	30	0.5	6.0	20.0	4.5	1.05	0.1	148.5	7.0	9.0	9.5	35.0	3.6
PC5 (39-96)	38	0.0	5.5	27.5	11.5	1.07	0.2	167.0	2.5	8.0	25.5	33.0	4.5
PC6 (0-3)	176	0.0	8.0	21.0	4.5	0.78	0.2	144.5	3.5	6.0	13.0	27.0	2.9
PC6 (60-63)	26	0.0	7.0	18.0	5.5	0.99	0.2	148.0	3.5	7.0	6.5	26.5	2.6
PC6 (120-123)	44	0.5	8.5	22.0	6.5	1.16	0.1	162.0	8.0	8.5	5.5	30.0	2.7
PC12 (0-2)	105	0.0	7.5	15.0	6.0	1.25	0.1	230.5	5.0	12.0	107.0	31.0	10.4
PC12 (92-95)	43	0.0	13.0	36.5	15.5	2.60	<0.1	187.5	7.5	40.0	2.0	44.0	0.8
PC12 (126-129)	55	0.0	17.0	7.5	8.5	2.12	0.2	375.0	4.5	18.0	10.5	33.5	2.9
PC12 (153-156)	64	0.0	10.5	23.5	12.0	2.31	0.1	186.0	10.0	19.0	21.0	49.5	6.2
PC14 (17-20)	31	0.0	10.5	10.5	22.0	2.64	0.1	152.5	22.5	17.5	6.5	71.0	2.7

Table 9b. Summary of the Trace Metal Geochemistry of Piston Cores

This table presents a summary of the trace metal geochemistry of sediments collected by piston coring (station locations in Figure 5). The analyses are average values for the following samples:

Anal. #1 - average analysis of surficial sediments from piston cores #2, #3, #4, #5 and #6.

Anal. #2 - average analysis of subsurface sediments from piston cores #2, #3, #4, #5, and #6.

Anal. #3 - average analysis of Beaumont Formation samples (subsurface samples of piston cores #12 and #14).

The concentration of carbonate and Fe are in %, all others in ppm.

	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Carbonate Content
Anal. #1	74	<0.5	6.5	15.5	7.5	0.89	<0.2	139.5	3.0	8.5	14.5	37.0	3.5
Anal. #2	38	<0.5	6.5	19.5	7.0	1.18	< 0.2	163.5	5.5	8.5	35.5	35.5	3.8
Anal. #3	48	0.0	13.0	19.5	14.5	2.42	< 0.2	225.5	11.0	23.5	49.5	49.5	3.2

Table 10a. Trace Metal Geochemistry of Trapped Suspended Sediments from Beneath Platform 288-A, Platform 296-B and Satellite Structure 288-3. This table presents the trace metal analysis of trapped suspended sediments from beneath platform 288-A, 296-B and satellite structure 288-3 collected during 11/12/77, 6/21/78 and 8/11/78. The traps were placed beneath the structures at water depths of approximately 1.5, 12.0 and 18.0 meters. Table 9 presents a description of the samples. The concentration of Fe is in %, all others in ppm. See Table 2 for sample descriptions.

Sample Location Date of Collection	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
Platform 288-A; 11/12/77												
1.	240	0.5	12.0	16.5	11.0	>0.90	0.2	505.0	31.0	20.0	23.0	201.5
2.	234	1.0	7.0	30.5	14.0	>0.90	0.1	425.0	34.0	137.5	35.0	249.0
3.	198	0.0	9.5	17.0	12.0	>0.90	0.2	300.0	30.5	20.0	10.0	77.0
4.	211	0.0	8.0	16.0	10.5	>0.90	0.3	318.0	29.0	26.0	18.0	103.5
5.	198	0.5	11.5	20.5	11.0	>0.90	0.2	352.5	31.5	27.5	21.5	120.0
6.	187	1.0	9.5	19.5	12.0	>0.90	0.2	287.0	28.5	32.0	27.0	97.5
7.	195	0.5	16.0	17.0	11.5	>0.90	0.4	232.5	28.5	34.0	28.0	160.0
8.	261	0.0	6.5	13.5	10.0	>0.90	0.1	400.0	27.0	20.0	18.5	67.5
9.	232	0.5	7.0	15.0	15.5	>0.90	0.1	332.5	29.0	18.5	16.0	152.5
10.	209	0.0	5.0	16.5	17.5	>0.90	0.0	217.5	31.5	17.5	12.5	225.5
Platform 296-B; 6/21/78												
11.	225	4.5	11.0	16.5	41.0	>1.0	0.1	117.0	0.0	23.0	22.5	537.5
12.	215	3.0	8.5	17.0	35.5	>1.0	0.2	157.5	1.5	18.5	21.0	215.0
13.	210	4.5	7.5	23.5	37.0	>1.0	0.2	119.0	0.0	21.0	18.0	193.5
14.	217	2.5	9.5	27.0	32.5	>1.0	0.1	213.5	2.5	22.5	24.5	243.0
15.	197	0.0	12.0	27.5	18.0	>1.0	0.1	234.0	2.5	19.5	28.0	265.5
16.	202	0.5	10.5	22.0	16.5	>1.0	0.2	237.0	5.0	20.5	19.5	178.0
17.	217	0.5	9.0	15.5	12.0	>1.0	0.1	249.5	7.5	15.0	11.5	94.5
Satellite 288-3; 6/21/78												
18.	186	2.0	10.5	4.5	20.0	>1.0	0.2	66.0	3.0	30.5	35.0	154.0
19.	212	0.5	15.5	3.0	27.5	>1.0	0.1	92.5	2.0	17.5	23.0	197.5
20.	241	0.0	16.0	1.0	32.0	>1.0	0.1	89.0	0.0	14.0	18.5	250.0
21.	212	0.0	7.0	4.0	33.0	>1.0	0.1	26.5	0.0	22.0	22.0	103.5
22.	242	0.0	12.0	17.5	33.5	>1.0	0.1	232.5	0.0	16.5	20.5	137.0
Platform 296-B; 8/11/78												
23.	263	4.0	9.0	26.0	11.5	>1.0	0.1	210.0	4.5	22.5	28.5	308.5
24.	224	2.5	8.5	21.0	8.5	>1.0	0.2	227.0	6.5	18.0	31.5	283.0
25.	196	1.0	5.0	17.0	10.5	>1.0	0.3	263.0	7.5	17.0	32.5	104.5
26.	178	2.0	6.5	16.0	11.5	>1.0	0.1	247.0	5.5	19.5	28.0	154.5
27.	183	0.0	7.0	11.5	9.5	>1.0	0.1	201.0	2.5	19.5	19.0	292.0

Table 10a. (cont'd.)

Sample Location Date of Collection	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
Satellite 288-3; 8/11/78												
28.	207	0.0	6.5	15.5	5.0	>1.0	0.2	238.0	11.5	25.5	20.5	156.0
29.	233	0.5	9.0	12.0	8.5	>1.0	0.1	212.5	8.0	28.0	22.0	89.5
30.	218	0.0	8.0	12.5	6.0	>1.0	0.1	226.5	10.0	36.0	24.5	46.0
31.	211	0.5	10.5	13.0	7.0	>1.0	0.1	221.5	10.5	27.0	20.0	178.0
32.	236	0.0	20.5	38.0	14.0	>1.0	0.2	437.5	5.5	21.0	14.0	211.5

Table 10b. Trace Metal Geochemistry of Pumped Suspended Sediment from Galveston Bay and the Buccanner Field.

This table presents the trace metal analysis of pumped suspended sediments from Galveston Bay and the Buccaneer Field from Anderson and Schwarzer (1977). The concentrations of Fe is in %, all others in ppm.

Sample	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
Galveston Bay												
G-10Y	*	2.5	9.5	113.0	91.0	>1.0	*	181.5	70.5	46.5	35.5	121.0
G-10Z	*	4.5	9.0	142.0	60.5	>1.0	*	556.5	47.0	43.0	11.0	416.0
Buccaneer Field												
B-8-N	*	<0.5	6.5	74.0	19.0	>1.0	*	736.0	34.5	35.5	22.0	65.0
B-8Q1	*	1.5	5.5	33.0	124.0	>1.0	*	186.5	51.0	30.5	19.5	141.0
B-8Q1	*	1.5	6.0	25.0	85.5	>1.0	*	254.0	36.5	26.0	15.5	96.0

* Insufficient sample

Table 11. Trace Metal Geochemistry of Produced Formation Waters (Brine) from Platforms 238-A and 296-B

This table presents the trace metal analysis produced in formation waters from platform A and B. The date when the samples were collected is given and all concentrations are in ppm. $\bar{X}$ gives the average for each platform.

Date Collected	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
					Platform 288-A							
6/26/77	4.0	<0.5	<0.5	<0.5	<0.5	4.0	<0.05	<0.5	1.0	0.5	47.5	<0.5
7/15/77	6.5	<0.5	<0.5	<0.5	<0.5	4.0	<0.05	<0.5	1.0	0.5	48.0	<0.5
8/21/77	5.0	<0.5	<0.5	<0.5	<0.5	4.0	<0.05	<0.5	1.0	0.5	48.0	<0.5
9/19/77	4.0	<0.5	<0.5	<0.5	<0.5	4.0	<0.05	<0.5	1.0	0.5	48.0	<0.5
$\bar{X}$	5.0	<0.5	<0.5	<0.5	<0.5	4.0	<0.05	<0.5	1.0	0.5	48.0	<0.5
					Platform 296-B							
7/16/77	1.5	<0.5	<0.5	<0.5	<0.5	12.5	<0.05	<0.5	0.5	0.5	30.0	1.0
6/26/77	2.5	<0.5	<0.5	<0.5	<0.5	9.5	<0.05	<0.5	0.5	0.5	34.5	<0.5
7/15/77	5.0	<0.5	<0.5	<0.5	<0.5	10.0	<0.05	<0.5	0.5	0.5	32.0	<0.5
9/18/77	2.0	<0.5	<0.5	<0.5	<0.5	8.0	<0.05	<0.5	0.5	0.5	35.5	<0.5
11/2/77	7.5	<0.5	<0.5	<0.5	<0.5	9.0	<0.05	<0.5	0.5	0.5	35.0	<0.5
$\bar{X}$	3.5	<0.5	<0.5	<0.5	<0.5	10.0	<0.05	<0.5	0.5	0.5	33.5	<0.5

Table 12. Summary of the first year's results of trace metals in the marine organisms of the Buccaneer Oil/Gas Field

The average concentrations and range of concentrations for selected trace metals in organisms from the Buccaneer Field Study are compared with similar data from BLM's South Texas Outer Continental Shelf Study. Data is presented only for those elements that were analyzed in both studies.

	Barnacles		Shrimp			
	NOAA		NOAA		BLM	
	Avg.	Range	Avg.	Range	Avg.	Range
Cd	19.20	11.00- 25.00	.8	.5 - 1.5	.12	.05- .33
Cr	2.70	<.10- 64.25	<.1	0 - <.1	2.10	.40- 3.80
Cu	18.20	12.50- 27.25	25.8	23.0 -46.5	24.30	22.50-28.50
Mn	10.62	5.50- 18.50	1.75	.5 - 3	--	---
Pb	7.80	3.50- 11.50	4.6	2 - 8.5	.95	.60- 1.80
Zn	200.80	151.50-281.00	108.0	99 -123	47.90	20.50-57.50

	Fish				Fish Liver			
	NOAA		BLM		NOAA		BLM	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Cd	<.10	0.00- <.10	.11	.05- .21	6.40	<.10- 15.25	3.70	.70- 6.10
Cr	5.90	<.10-61.75	1.30	1.00- 2.00	6.60	<.10- 26.25	2.20	2.00- 2.20
Cu	2.60	.50- 5.50	.66	.50- .90	72.80	25.00-154.00	14.70	9.00- 15.00
Mn	<.10	0.00- <.10	.18	.10- .30	4.80	1.50- 7.75	3.40	3.00- 4.70
Pb	<.10	0.00- <.10	1.30	.30- 2.90	9.10	6.00- 13.50	2.80	1.00- 7.60
Zn	41.60	24.25-85.50	10.20	.60-11.70	86.80	25.50-130.75	146.40	100.00-268.00

Table 12. Continued.

	Plankton				Squid			
	NOAA		BLM		NOAA		BLM	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Cd	<.10	.00- <.10	4.72	.86- 5.25	<.10	.00- <.10	1.03	.91- 1.18
Cr	88.30	55.25-120.25	18.00	1.90-82.00	2.75	2.50- 3.00	4.70	3.00- 6.10
Cu	78.00	47.25-100.00	14.20	2.70-61.00	15.00	13.00- 17.00	65.70	61.00- 69.00
Mn	82.10	57.00-101.00	---	---	2.00	1.50- 2.50	---	---
Pb	334.30	185.25-469.00	42.40	3.10-474.00	4.50	4.25- 4.75	2.00	1.30- 2.70
Zn	222.75	205.50-234.25	134.10	26.50-560.00	60.50	53.75- 67.25	144.00	50.00-290.00

Table 13. Estimated Analytical Error For Biological Samples

This table reports the estimated analytical error (standard deviation in %) based on duplicate analysis of numerous sample solutions. The analytical error is estimated individually for sediments (see Table 5) and for biological samples (this Table). The number in parenthesis is the number of duplicate samples used to estimate the analytical error of that particular element.

Element	Estimated Analytical Error for Biological Samples	
Ba	10%	(9)
Cd	16%	(11)
Co	13%	(13)
Cr	15%	(12)
Cu	13%	(15)
Fe	11%	(10)
Hg	20%	(8)
Mn	12%	(12)
Ni	24%	(14)
Pb	15%	(10)
Sr	5%	(11)
Zn	9%	(12)

Table 14a. Duplicated Analysis of Biological Samples

This table presents the analysis of duplicated samples, i.e. two aliquots of the same homogenized sample were prepared and analyzed. All values in ppm.

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
F28	0	0.0	0.5	8.5	3.5	9.5	0.2	1.0	5.0	3.5	1.0	71.5
	0	0.5	1.0	5.5	5.0	15.0	0.1	1.5	0.0	5.5	1.0	79.5
F30	3	0.0	1.0	0.0	4.0	19.0	0.2	6.5	2.0	4.0	2.0	120.0
	2	0.5	0.5	0.0	3.5	17.5	0.3	1.5	3.5	2.5	1.0	139.5
B59	18	19.0	3.5	0.0	28.0	64.0	0.2	7.5	4.0	0.5	15.0	122.5
	19	12.5	0.0	0.0	18.5	112.0	0.1	15.5	2.0	1.0	16.0	222.5
B55	48	21.0	0.0	0.0	16.5	473.5	0.1	15.0	40.0	0.0	180.0	125.0
	56	18.5	2.0	0.0	11.0	422.0	0.2	29.0	30.0	0.0	325.0	275.0
CR35A	0	1.0	2.5	0.0	32.5	30.5	0.1	16.5	19.0	0.0	8.0	56.5
	1	0.5	3.0	0.0	27.0	42.0	0.0	10.0	25.0	1.0	5.0	62.0
CR34D	1	66.0	93.5	9.0	203.0	141.0	0.1	14.0	5.5	0.0	5.0	2500.0
	2	65.5	85.0	8.0	328.0	107.5	0.2	15.0	3.5	0.0	6.0	1610.0
CR50	150	3.0	11.0	0.0	16.0	1350	0.4	192.0	24.5	9.0	655.5	175.0
	115	1.0	2.0	0.0	14.5	1175	0.6	290.0	27.5	5.0	438.0	180.0

Table 14b. Estimated Sampling Error For Biological Samples

This table presents the estimated sampling error (which includes the analytical error reported in Table 13) based on the duplicated analysis given in Table 14a.

Element	Estimated Sampling Error
Ba	20%
Cd	30%
Co	50%
Cr	20%
Cu	20%
Fe	20%
Hg	25%
Mn	40%
Ni	28%
Pb	29%
Sr	24%
Zn	22%

Table 15. Trace Metal Concentrations in Fish

This table presents the trace metal concentrations in fish caught near structures in the Buccaneer Oil/Gas Field. All concentrations are in ppm. Sample designations are as follows:

(1) The first 3 or 4 letters and numbers beginning with F are laboratory sample numbers; samples F28A and F30A are duplicates of F28 and F30 respectively.

(2) The next series of 2 or 3 letters identifies the type of fish.

a) SF - spadefish (Chaetodipterus faber), upper water column, grazes on fouling community.
b) GTF - gray triggerfish (Balistes capricus), top to bottom, grazes on fouling community, particularly barnacles.
c) RS - red snapper (Luljanus campechanus), bottom dweller, predator.
d) SH - sheepshead (Archosargus probatocephalus), upper water column, grazer on barnacles.
e) SPF - soapfish (Rypticus maculatus), habit unknown, probably a small predator.
f) PF - pinfish (Lagodon rhomboides), small grazer.
g) T - tomtate (Haemulon aurolineaturn), small grazer.
h) BM - blackedge moray (Gymnothorax nigromar-ginatus), reef predator.
i) YC - yellow chub (Kyphosus incisor), surface, seasonal grazer on fouling community.
j) BC - bermuda chub (Kyphosus sectatrix), grazer.
k) CB - crested blenny (Hypleurochilus germinatus), small predator.
l) RSD - rough scad (Decapterus punctatus), pelagic baitfish, plankton feeder.
m) LT - little tunny (Euthynnus alletteratus), pelagic predator, upper water.

(3) The next 2 numbers are the original sample numbers assigned by the NMFS/LGL dive team when they collected the samples.

(4) The next 2 letters identify the tissue analyzed, BA (back muscle), BE (belly muscle), and WF (whole fish).

(5) The next letter identifies the sex of the fish, if determined, F (female) and M (male).

(6) The next 2 letters identify the location where the particular specimen was obtained, PA (production platform A), QA (quaters platform A), CF (control station F), and BF (Buccaneer Field).

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
F28 SF.02.BA.PA	0	0.0	0.5	8.5	3.5	9.5	0.2	1.0	5.0	3.5	1.0	71.5
F28A SF.02.BA.PA	0	1.0	1.0	5.5	3.5	15.0	0.3	1.5	0.0	5.5	1.0	79.5
F33 SF.13.BE.F.QA	4	1.0	0.5		5.0	23.0	0.1	1.0	2.5	4.0	2.0	35.5
F34 SF.13.BA.F.QA	2	0.5	1.0	22.5	3.0	14.0	0.3	1.0	0.0	2.5	0.5	32.0

Table 15. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
F35 SF.14.BE.M.QA	10	0.0	1.0		2.0	36.0	0.2	2.5	0.5	5.5	7.5	28.5
F36 SF.14.BA.M.QA	0	0.0	1.0	11.0	3.5	14.5	0.3	1.0	0.0	3.5	0.5	21.5
F37 SF.15.BE.M.QA	5	0.0	0.0	11.5	3.0	17.5	0.2	1.0	2.5	5.0	1.0	43.0
F38 SF.15.BA.M.QA	3	0.0	0.0	1.0	2.5	31.5	0.3	1.5	4.5	3.5	0.5	65.5
F40 SF.16.BA.F.QA	2	0.0	0.0	0.0	8.0	14.5	0.3	1.0	0.0	3.0	3.0	144.0
F41 SF.17.BE.M.QA	4	0.0	1.5	0.0	11.5	19.5	0.1	2.0	10.5	3.5	2.0	71.5
F42 SF.17.BA.M.QA	2	1.0	0.5	0.0	3.5	24.5	0.2	1.5	4.5	3.5	1.0	72.0
F43 SF.18.BE.M.QA	0	0.0	1.5		2.5	14.0	0.2	1.0	3.0	5.0	1.5	69.0
F44 SF.18.BA.M.QA	0	0.5	0.0	3.0	2.5	14.5	0.4	1.0	0.0	3.0	0.5	33.0
F67 SF.19.BE.M.QA	2	1.0		0.0		12.5	0.3	1.0	3.0	2.5	1.5	23.0
F68 SF.19.BA.M.QA	2	0.5	1.0	0.0	2.5	11.5	0.2	1.0	6.5	3.0	0.0	33.5
F69 SF.20.BE.M.QA	0	0.0	4.5	0.0	2.5	21.0	0.5	0.5	5.5	1.5	1.0	27.5
F70 SF.20.BA.M.QA	0	0.0		67.5		19.5	0.2	0.5	0.0	2.5	1.5	33.5
F53 SF.11.BE.F.CF	33	0.0	0.0	0.0	3.0	21.5	0.4	6.5	8.0	7.5	16.5	31.0
F54 SF.11.BA.F.CF	17	1.0	0.5	0.0	1.5	11.0	0.1	1.0	1.5	2.5	0.5	22.0
F55 SF.12.BE.F.CF	10	0.0		2.5	2.0	13.0	0.3	5.0	0.0	4.5	3.0	27.5
F56 SF.12.BA.F.CF	0	0.0		11.0	2.5	14.5	0.5	1.0	0.5	1.5	0.5	26.0
F57 SF.10.BE.F.CF	13	0.0	3.5	1.0	2.5	9.5	0.2	8.5	5.0	3.5	6.5	26.5
F58 SF.10.BA.F.CF	0	0.0	8.0	11.5		5.5	1.5	1.5	1.5	3.5	1.0	19.0
F61 SF.09.BE.F.CF	0	1.5	0.5	0.0	2.5	15.0	0.4	9.5	2.0	4.5	4.0	25.0
F62 SF.09.BA.F.CF	12	1.0		0.0	2.0	12.0	0.6	1.0	4.0	3.5	1.0	30.3
F29 GTF.03.BA.PA	5	1.5	1.5	0.0	4.0	30.5	0.1	3.5	1.5	6.5	1.0	91.5
F30 GTF.03.BA.PA	3	0.0	1.0	0.0	4.0	19.0	0.2	6.5	2.0	4.0	2.0	120.0
F30A GTF.03.BA.PA	2	0.5	0.5	0.0	3.5	17.5	0.3	1.5	3.5	2.5	1.0	139.5
F46 GTF.21.BA.F.QA	0	0.5	1.5	9.5	3.5	53.0	0.3	4.5	6.5	3.0	1.5	30.0
F48 GTF.22.BA.F.QA	0	0.5	0.0	0.0	3.0	32.5	0.2	2.5	1.5	3.5	1.0	25.5
F45 GTF.21.BE.F.QA	2	0.0	0.0	13.0	2.5	17.5	0.2	3.5	5.5	3.5	2.0	56.0
F47 GTF.22.BE.F.QA	3	1.5	2.0	2.0	3.0	22.5	0.1	6.5	1.5	4.5	6.5	61.5
F31 RS.01.BE.PA	3	1.0	2.0	0.0	2.5	17.0	0.5	1.0	2.5	4.5	3.0	103.0
F32 RS.01.BA.PA	0	0.5	1.5	19.0	3.5	17.0	0.4	1.0	0.5	4.0	1.0	160.5
F49 RS.23.BE.QA	2	0.5	0.0	0.0		32.5	0.4	3.0	1.0	4.5	4.0	24.5

Table 15. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
F50 RS.23.BA.QA	3	0.0	0.0	0.0		18.0	0.2	2.0	3.5	2.5	0.5	19.0
F51 RS.24.BE.QA	4	0.5	0.0	0.0	2.5	17.5	0.4	2.5	3.5	4.5	4.0	25.5
F52 RS.24.BA.QA	2	0.0	0.0	0.0	2.0	12.5	0.3	1.0	0.0	4.0	0.5	19.5
F77 RS.25.BE.QA	5	0.0		6.5	2.5	29.0	0.5	2.5	2.0	4.5	6.0	24.5
F78 RS.25.BA.QA	0	1.0	0.0	0.0	2.0	10.5	0.4	1.0	0.0	3.0	0.0	15.0
F74 SH.05.BA.M.CF	0	0.0		4.0	2.5	10.5	0.2	1.5	8.0	2.5	0.5	56.0
F75 SH.06.BE.M.CF	0	0.0		3.5	6.5	20.5	0.3	4.0	0.0	4.5	1.5	319.5
F76 SH.06.BA.M.CF	2	0.0	0.0	13.5	2.0	11.5	0.3	0.5	1.0	4.0	0.0	19.5
F86 SH.32.WF.QA	0	0.5	0.0	0.5	2.5	9.5	0.2	1.0	0.0	2.0	0.0	26.5
F87 SH.33.WF.QA	0	0.0	0.0	0.0	1.5	20.5	0.5	1.0	0.0	3.0	1.0	25.5
F88 SH.31.WF.QA	0	0.5	0.0	0.0	2.0	70.0	0.3	1.5	3.0	2.5	0.0	26.0
F90 SPF.34.WF.QA	5	0.0		0.0	1.0	8.5	1.2	2.5	5.0	3.5	3.5	92.0
F91 SPF.35.WF.QA	6	1.0		0.0	1.5	18.0	0.8	1.5	3.0	4.5	4.5	33.5
F92 SPF.36.WF.QA	8	0.0	0.0	0.0	30.5	21.5	0.5	2.0	22.0	15.5	11.5	48.5
F79 PF.27.BE.QA	5	0.0		0.0	2.5	28.0	0.3	1.0	1.5	3.5	0.5	28.0
F80 PF.27.BA.QA	9	1.5	2.5	6.5	2.5	26.5	0.3	1.0	0.5	2.5	0.5	53.0
F82 T.29.BA.QA	3	0.0		0.0	2.0	12.0	0.4	1.0	0.0	4.0	2.5	20.0
F83 B.30.BA.QA	2	1.0	1.0	0.0	4.0	18.5	0.6	2.0	17.0	4.5	2.0	84.0
F84 BM.26.BA.QA	8	0.0	2.5	0.0	3.0	56.5	0.8	11.5	5.5	8.0	13.0	39.5
F85 BM.26.BE.QA	0	0.0	0.0	1.5	3.5	16.5	1.0	2.0	1.0	5.0	4.5	36.0
F60 YC.08.BA.CF	5	1.0	3.5	3.5	3.5	16.5	0.2	0.5	0.0	0.5	1.5	55.0
F65 CB.41.44.WF.CF	3	1.5	0.5	0.0	6.5	121.0	0.1	0.0	17.5	15.5	95.5	77.5
F66 RSD.07.BA.Cf	2	1.0		0.0			0.4	3.0	8.0		13.0	70.0
F72 LT.40.BA.F.BF	4	0.0		0.0	3.0	54.0	0.1	1.0	4.0	2.0	0.0	26.0
F89 BC.37.WF.QA	8	1.0		0.0	3.0	37.0	0.2	1.0	0.5	3.5	1.5	108.0
F24	6	1.5	4.0	93.0	3.5	47.5	0.5	2.5	2.5	4.0	2.0	32.5
F25		0.0	0.0	10.5	3.0	30.5	0.4	2.5	0.0	4.5	1.5	16.5
F26	8	1.0	0.0	1.0		30.0	0.8	1.0	2.5	3.0	1.0	26.5

Table 16. Trace Metal Concentrations in Fish Livers

This table presents the trace metal concentrations in fish livers from Fish caught near structures in the Buccaneer Oil/Gas Field. The sample identification is the same as in table 15. The first 3 characters beginning with L are laboratory sample numbers. The other L appearing in the sample identification stands for Liver. All concentrations are in ppm.

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
L11 SF.02.L.PA	2	18.5	2.5	0.0	28.5	1,395.0	0.1	8.0	0.0	3.5	1.0	125.5
L15 SF.13.L.F.QA	2	16.5	4.0	2.5	56.0	2,340.0	0.2	10.0	0.0	5.5	1.0	142.0
L16 SF.14.L.M.QA	3	52.3	2.5	0.0	13.0	1,680.0	0.1	6.0	0.0	2.5	1.0	128.5
L17 SF.15.L.M.QA	2	32.5	3.0	11.5	44.5	2,310.0	0.2	11.0	3.0	4.0	3.0	158.5
L19 SF.17.L.M.QA	2	30.5	2.5	0.0	49.0		0.4	12.0	9.0	5.0	2.0	165.5
L20 SF.18.L.M.QA	0	21.5	3.0	3.5	25.5	1,500.0	0.0	5.5	0.0	7.5	1.5	103.0
L28 SF.19.L.M.QA	3	42.5	2.0	0.0	44.5	2,040.0	0.3	11.0	4.5	4.0	3.0	128.0
L29 SF.20.L.M.QA	0	60.0	1.5	0.0	46.0	4,390.0	0.2	6.5	1.0	2.0	2.0	161.5
L24 SF.11.L.F.CF	3	5.0	3.0	2.0	25.5	1,920.0	0.4	10.0	0.0	2.5	2.0	112.0
L25 SF.09.L.F.CF	3	4.5	4.5	0.0	32.0	2,690.0	0.2	9.0	0.0	15.0	0.5	117.0
L26 SF.12.L.F.CF	2	3.0	11.0	0.0	182.5	2,250.0	0.1	5.0	5.5	3.5	2.0	102.0
L27 SF.10.L.F.CF	2	6.5	2.5	0.0	37.0	1,660.0	0.2	10.5	0.0	4.0	2.0	125.0
L13 RS.01.L.PA	0	1.5	1.0	16.0	18.5	430.0	1.1	6.0	0.0	4.0	2.0	180.5
L23 RS.23.L.QA	2	2.0	1.5	5.5	10.5	405.0	0.3	5.0	4.5	2.5	1.0	96.5
L32 SH.05.L.M.CF	0	4.5	4.0	0.0	112.0	1,230.0	0.4	19.0	5.0	5.5	3.5	204.5
L33 SH.06.L.M.CF	0	8.5	3.5	1.5	24.0	1,840.0	0.3	17.5	3.0	6.0	1.5	310.5
L30 BM.26.L.QA	2	0.0	1.5	1.5	14.5	1,000.0	0.2	3.0	4.5	3.5	0.0	174.5
L34 LT.04.L.M.BF	2	9.0	3.0	0.0	25.5	450.0	0.1	6.5	4.0	5.0	4.5	937.5

Table 17. Trace Metal Concentrations in Barnacles

This table represents the trace metal concentrations in barnacles taken from structures in the Buccaneer Oil/Gas Field. All concentrations are in ppm. Sample identifications are as follows:

(1) The first 3 characters beginning with B are laboratory sample numbers.

(2) The next letter B identifies the sample as a barnacle.

(3) The next 1 or 2 numbers are the original sample numbers assigned by the NMFS/LGL dive team when they collected the samples.

(4) The next 2 or 3 letters identifies the location where the particular specimen was obtained, PA (production platform A), QA (quarters platform A), CF (control station F), PB (production platform B), QB (quarters platform B), and CB (control station B). Two special designations are PB.FIB (barnacle growing on fiberglass from platform B) and FSA (barnacle from flarestack, platform A)

(5) The next 1 or 2 letters designate the environment in which the barnacles were growing as NA (nonaffected by brine discharge) and as A (affected by bring discharge).

(6) The last series of characters designate the water depth at which the barnacles were growing, S (surface) or 18 (18 meters depth).

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
B33 B.2.PA.NA.S	15.0	19.0	0.5	11.0	17.5	70.0	0.1	8.5	10.5	7.5	20.0	201.5
B36 B.12.PA.NA.18	16.0	16.0	1.5	31.5	29.0	194.5	0.1	13.0	14.0	9.5	23.5	675.0
B41 B.4.QA.NA.S	17.0	18.0	0.5	0.0	15.5	204.5	0.1	12.0	8.5	6.5	21.0	135.5
B38 B.14.QA.NA.18	72.0	25.0	1.0	0.0	3.5	248.5	0.2	26.0	2.0	7.0	398.0	34.5
B58 B.24.QA.NA.S	126.0	22.0	5.5	2.5	39.5	418.5	0.1	20.0	12.0	2.0	248.0	200.0
B55 B.34.QA.NA.18	48.0	21.0	0.0	0.0	16.5	473.5	0.1	15.0	40.0	0.0	180.0	125.0
B37 B.6.CF.NA.S	26.0	16.5	2.0	0.0	15.0	59.0	0.2	11.0	8.0	7.5	22.0	179.5
B31 B.26.CF.NA.S	66.0	25.0	0.5	1.5	17.5	192.5	0.0	16.0	22.0	10.0	139.5	137.0
B32 B.16.CF.NA.18	30.0	30.0	0.0	0.0	6.5	148.0	0.8	15.5	16.0	9.5	27.5	9.0
B44 B.8.PB.NA.S	36.0	26.0	0.5	0.0	14.5	127.0	0.3	15.0	55.0	6.5	12.5	290.5
B46 B.10.QB.NA.S	55.0	28.5	2.5	0.0	20.0	121.0	0.4	11.5	14.5	8.0	23.0	172.5
B47 B.20.QB.NA.18	164.0	24.5	0.5	0.0	20.0	178.5	0.1	25.5	23.0	18.0	409.0	725.0
B48 B.40.QB.NA.18	121.0	17.5	3.0	0.0	15.0	302.0	0.1	26.5	13.5	10.5	87.0	440.0
B60 B.40.QB.NA.18	68.0	23.5	3.0	0.0	18.0	179.5	2.2	17.5	6.0	0.0		130.0
B34 B.1.PA.A.S	17.0	22.0	0.5	2.0	14.5	147.5	0.1	10.0	3.5	6.0	12.5	204.0

Table 17. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
B35 B.11.PA.A.18	37.0	23.5	0.0	0.0	37.5	278.0	0.2	14.0	16.0		61.0	700.0
B56 B.31.PA.A.18	35.0	24.0	7.5	0.0	18.5	195.0	0.1	8.0	5.5	3.0	54.0	245.0
B42 B.3.QA.A.S	60.0	15.5	2.5	0.0	16.5	62.0	0.2	12.0	5.5	7.5	50.5	176.5
B43 B.13.QA.A.18	145.0	20.5	3.0	0.0	11.0	116.0	0.1	21.5	23.0	14.0	343.0	176.0
B59 B.23.QA.A.S	18.0	19.0	3.5	0.0	28.0	64.0	0.1	7.5	4.0	0.0	15.0	122.5
B39 B.5.CF.A.S	20.0	24.0	7.5	0.0	24.0	111.5	0.2	10.0	8.5	5.5	16.5	298.5
B40 B.15.CF.A.18	27.0	20.5	1.0	0.0	16.5	117.5	0.1	18.5	14.0	10.0	41.0	315.5
B30 B.35.CF.A.18	30.0	20.5	3.5	0.0	17.5	107.0	0.1	13.0	7.0	0.0	73.0	150.0
B49 B.7.PB.A.S	37.0	20.0	0.0	0.0	15.0	128.5	0.1	13.0	10.5	6.5	20.0	174.5
B53 B. 17.PB.A.18	111.0	1.0	6.0	0.0	19.5	21.5	0.1	15.5	63.5	37.0	260.0	195.0
B54 B.27.PB.A.S	93.0	0.0	7.5	0.0	7.5	30.0	0.2	10.0	71.5	40.5	315.0	115.0
B51 B.9.QB.A.S	15.0	0.0	7.0	0.0	6.5	32.5	0.2	44.0	6.5	38.5	32.0	7.5
B45 B.PB.FIB	52.0	23.0	1.5	0.0	22.5	104.0	0.2	18.5	7.5	10.0	31.0	280.5
B50 B.CB	149.0	13.0	9.0	0.0	12.0	139.5	0.1	18.5	12.5	6.0	915.5	145.0
B52 B.CB	15.0	3.0	1.5	0.0	7.0	17.0	0.1	5.5	3.5	0.0	29.0	6
B57 B.FSA	73.0	19.5	8.5	3.0	17.0	122.0	0.1	16.0	8.5	2.0	68.0	152.5
B23	27.0	0.0	0.0	4.0	22.0	316.5	0.1	8.0	9.0	12.5	19.0	285.5

Table 18. Trace Metal Concentrations in Benthos

This table presents the trace metal concentrations in benthos collected about the structures in the Buccaneer Oil/Gas Field. All concentrations are in ppm. Sample identifications are as follows:

(1) The first 4 to 5 characters beginning with CR are laboratory sample numbers.

(2) The next 1 to 3 letters identify the type of organism.

- a) HC - horse conch (Pleuroploea gigantea)
- b) AWO - Atlantic winged oyster (Pteria colymbus)
- c) BTS - banded tulip-shell (Fasciolaria hunteria)
- d) SM - spiny murex (Murex fluvescens)
- e) YSC - yellow soft coral (Alcyonaria #1)
- f) BSC - brown soft coral (Alcyonaria #2)
- g) H - hydroid
- h) AC - arrow crab (Stenorynchus seticornis)
- i) O - octopus (Ocyopus vulgaris)
- j) HCR - hermit crab (Paguridae)
- k) MP - (Murex pomum)

(3) The next 2 numbers are the original sample numbers assigned by the NMFS/LGL dive team when they collected the samples.

(4) The next 1 to 2 letters for the hourse conch (HC) samples only identify the tissue snalyzed, P (pedicle), MS (midsection), M (muscle), and L (liver).

(5) The next 2 letters identify the location where the particular specimen was collected, PA (production platform A), QA (quarters platform A), CF (control station F), CB (control station B), and FA (flarestack A).

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
CR14 HC.08.P.CF	2.0	1.5	1.5	1.0	110.5	242.0	0.1	16.5	11.0	4.0	10.5	308.5
CR25A HC.05.P.QA	3.0	0.5	1.5	0.0	26.0	129.5	0.0	12.0	2.5	3.5	7.5	69.0
CR34A HC.01.P.QA	3.0	4.5	5.0	0.0	28.5	49.5	0.2	12.5	3.5	0.0	14.0	52.5
CR35A HC.06.P.CB	0.0	1.0	2.5	0.0		30.5	0.1	16.5	19.0	0.0		56.5
CR36 HC.02.P.PA	0.0	1.0	3.5	0.0	23.8	50.5	0.3	13.0	2.0	0.0	9.5	85.5
CR37 HC.07.P.CB	0.0	1.0	6.0	0.0	40.5	33.0	0.0	11.0	16.5	0.0	17.0	58.0
CR38A HC.08.P.CB	14.0	0.5	2.0	0.0	42.5	20.0	0.2	9.5	4.5	0.0	17.0	54.5
CR39 HC.30.P.FA	25.0	0.0	5.0	0.0	21.5	35.5	0.2	9.5	181.5	0.0	18.0	570.0

Table 18. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
CR40A HC.30.P.FA	125.0	1.0	5.0	5.9	38.8	99.0	0.2	14.5	3.5	0.0	10.5	96.0
CR40B HC.30.Ms.FA	10.0	10.5	0.0			116.9	0.3	17.5	2.0	6.0	12.5	92.0
CR38B HC.08.MS.CB	17.0	6.0	4.0	0.0	83.0	84.0	0.8	10.5	12.5	4.0	28.0	101.5
CR35B HC.06.MS.CB	0.0	77.5	4.0	9.8	556.5	8.5	0.5	10.0	7.0	0.0	15.0	80.5
CR34B HC.01.MS.PA	3.0	2.5	1.0	2.0	7.5	38.0	0.3	1.0	5.5	0.0	4.5	1,100.0
CR25B HC.05.MS.QA	6.0	19.0	1.5	17.0	522.0	720.0	0.4	14.0	9.5	9.5	8.0	975.0
CR35C HC.06.M.CB	4.0	17.5	4.5	0.0	367.5	143.0	1.0	16.5	7.5	4.5	19.0	115.5
CR34C HC.01.M.PA	8.0	17.5	0.0	0.0	0.0	0.0	0.0	13.5	2.0	0.0	14.0	89.0
CR38C HC.08.L.CB	19.0	49.5	4.0	1.0	222.0	102.5	0.2	5.5	6.0	0.0	9.0	880.0
CR34D HC.01.L.PA	1.0	66.0	93.5	9.0	203.0	141.0	0.1	14.0	5.5	0.0	5.0	2,500.0
CR35 HC.06.L.CB	8.0	75.5	4.5	0.0	535.5	117.6	0.1	10.0	3.5	0.0	10.0	1,300.0
CR25C HC.05.L.QA	6.0	133.0	2.5	0.0	56.0	354.0	0.2	13.0	17.5	5.5	5.5	1,100.0
CR27 AWO.10.1.CF	0.0	37.0	0.5	7.0	12.5		0.1	53.0	7.0	7.5	5.5	1,600.0
CR28 AWO.10.2.CF	53.0	29.5	1.5	2.5	15.0	115.5	0.2	99.5	22.0	9.5	1.0	1,350.0
CR32 AWO.03.PA	14.0	12.5	0.0	0.0	2.5	103.0	0.4	18.0	9.5	1.5	2.5	2,370.0
CR33 AWO.04.PA	9.0	16.5	4.0	0.0	5.5	87.0	0.3	8.5	2.0	0.0	22.0	1,400.0
CR43 AWO.21.CB	34.0	17.5	5.5	0.0	6.0	105.5	0.2	39.0	9.5	0.0	32.0	1,000.0
CR44 AWO.22.CB	10.0	23.0	2.5	0.0	4.0	87.5	0.1	12.5	0.5	0.0		1,550.0
CR45 AWO.23.CB	34.0	2.0	4.5	0.0	6.5	112.0	0.4	16.5	4.0	0.0	14.0	1,290.0
CR46 AWO.24.1.CB	14.0	20.0	2.5	0.0	23.5	114.3	0.2	27.0	0.0	5.0	4.0	1,165.0
CR47 AWO.24.2.CV	13.0	34.0	2.0	0.0	13.0	269.5	0.3	19.0	1.0	5.5	7.5	1,400.0
CR13 BTS.09.CF	4.0	2.0	1.0	0.0	53.0	225.0	0.1	7.0	3.5	3.5	5.5	131.0
CR29 BTS.26.FA	8.0	0.0	3.5	0.0	40.0	16.5	0.2	5.5	3.5	0.0	19.0	73.5
CR30 BRS.5.PA	6.0	1.5	3.5	0.0	25.0	72.5	0.2	4.5	75.0	0.0	48.0	190.0
CR5 SM.07.1.CF	12.0	62.5	0.0	0.0	27.5	416.5	0.3	9.5	5.0	7.5	24.0	1,050.0
CR6 SM.07.a.CF	7.0	3.0	0.5	0.0	27.5	107.0	0.2	6.5	2.5	5.5	12.5	112.5
CR7 SM.07.3.CF	11.0	94.5	1.0	0.0	26.5	492.5	0.1	9.5	3.0	6.5	25.0	965.0
CR8 SM.07.4.CF	13.0	116.5	2.0	0.0	53.5	486.5	0.0	7.5	25.	6.5	13.5	1,150.0
CR9 SM.07.5.CF	17.0	34.5	0.0	0.0	82.5	233.0	0.2	9.5	5.0	7.5	25.0	875.0
CR10 SM.07.6.CF	11.0	118.5	0.5	0.0	26.5	880.0	0.4	9.5	4.5	8.5	21.5	1,025.0

Table 18. continued

Sample Number	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn
CR20 SM.04.1.QA	10.0	71.5	1.5	0.0	124.5	920.0	0.1	8.0	7.5	5.0	25.0	1,250.0
CR21 SM.04.2.QA	9.0	77.0	2.5	0.0	112.0	1,425.0	0.2	24.5	25.5	11.5	244.0	1,350.0
CR22 SM.04.3.QA	8.0	93.0	1.0	0.0	51.0	760.0	0.2	8.0	2.5	6.5	14.0	1,175.0
CR23 SM.04.4.QA	9.0	58.5	2.5	0.0	36.0	504.1	0.1	10.5	6.0	11.5	18.0	975.0
CR24 SM.04.5.QA	7.0	105.0	2.0	0.0	74.5	4,090.0	0.1	18.5	13.0	9.5	48.5	1,550.0
CR12 SM.EGGS	30.0	2.0	1.0	44.5	22.5	1,325.0	0.3	6.5	5.0	8.5	10.5	298.5
CR1 YSC.13.CF	299.0	1.5	1.5	1.0	14.5	262.0	0.3	19.5	42.5	31.0	900.5	44.0
CR19 YSC.6.QA	273.0	1.5	2.5	2.0	14.5	316.0	0.2	22.5	51.0	35.5		84.5
CR2 BSC.14.CF	268.0	3.5	13.5	15.5	5.5	775.0	0.3	40.0	22.0	12.0		650.0
CR49 BSC.25.CB	244.0	4.0	11.0	5.7	17.5	184.0	0.3	18.0	15.5	9.0	977.5	49.0
CR48 BSC.17.CB	206.0	3.5	10.5	6.4	7.0	53.0	0.2	12.0	17.0	2.0	805.0	56.0
CR3 H.15.CF	100.0	4.0	3.0	16.5	40.0	2,530.0	0.3	0.0	24.5	21.5	73.5	149.0
CR3B H.15.CF	0.0	2.0	1.5	0.0	24.5	17.5	0.2	8.0	1.0	0.0	13.0	63.5
CR50 H.18.CB	150.0	3.0	11.0	0.0	16.0	1,350.0	0.4	192.0	24.5	9.0	655.5	175.0
CR15 AC.11.CF	407.0	0.5	1.0	0.0	29.0	195.0	0.2	109.5	43.0	30.0		90.5
CR16 0.02.M.QA	4.0	0.5		0.0	30.0	183.5	1.1	5.0	11.5	4.5	5.0	117.5
CR18 HCR.03.QA		2.0	2.5	1.0	176.0	0.0	0.1	0.0	42.5	12.5	850.0	141.5
CR31 MP.31.FA	13.0	16.5	1.0	0.0	43.5	338.5	0.6	6.5	7.5	7.0	17.5	950.0

Table 19. Summary of the Trace Metals in Marine Organisms of the Buccaneer Oil/Gas Field

This table presents a summary of the trace metal concentrations in marine organisms of the Buccaneer Oil/Gas Field that are reported individually in Tables 15, 16, 17 and 18.
All concentrations are in ppm.
Common names are used in this table, scientific names are given in the tables of individual data.

Sample Type	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Number of Samples In Average
FISH													
All Fish	2.5	0.5	1.0	5.5	3.0	23.0	0.3	2.5	3.5	4.0	4.0	53.5	64
Spadefish	3.0	0.5	1.0	6.5	3.0	17.0	0.3	2.0	3.0	3.5	2.5	43.5	25
Grey Triggerfish	2.0	1.0	1.0	3.0	3.5	28.0	0.3	4.0	3.0	4.5	2.0	77.0	8
Red Snapper	1.5	0.5	0.5	3.0	2.0	19.0	0.4	1.5	1.5	4.0	2.5	49.0	8
Sheepshead	0.0	<0.5	0.0	3.5	2.5	24.0	0.3	1.5	2.0	3.0	0.5	79.0	6
Soapfish	4.5	0.5	0.0	0.0	11.0	13.0	0.8	2.0	10.0	8.0	6.5	58.0	3
FISH LIVERS													
All Fish Livers	1.0	17.5	3.0	2.5	45.0	1641	0.4	9.0	2.5	4.5	2.0	193.0	18
Spadefish Livers	2.5	24.5	3.5	1.5	48.5	2198	0.3	9.0	2.0	5.0	2.0	130.5	12
Red Snapper Livers		2.0	1.5	10.0	14.5	418	0.7	5.5	2.5	3.5	1.5	138.5	2
Sheepshead Livers	0.0	6.5	4.0	1.0	68.0	1535	0.4	18.5	4.0	6.0	2.5	247.5	2

Table 19. continued

Sample Type	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Zn	Number of Samples In Average
						BARNACLES							
All Barnacles	57.0	18.0	3.0	2.0	17.5	157.0	0.3	15.5	16.5	9.5	124.0	230.5	32
Barnacles (not affected)	63.5	21.5	2.0	4.0	18.5	215.0	0.4	17.0	17.0	7.0	120.5	285.5	12
Barnacles (affected)	51.5	16.0	4.0	<0.5	18.0	109.0	0.2	15.5	19.5	14.0	102.0	227.5	12
						BENTHOES							
Hourse Conch "Pedicle"	19.0	1.0	3.5	1.0	37.0	76.5	0.2	13.0	27.0	1.0	11.5	150.0	9
Hourse Conch "Mid section"	7.0	23.0	2.0	6.0	234.0	193.5	0.3	10.5	7.5	4.0	13.5	470.0	5
Hourse Conch "Liver"	8.5	81.0	26.0	2.5	254.0	179.0	0.2	10.5	7.0	1.5	7.5	1170	4
Atlantic Winged Oyster	20.0	21.5	2.5	1.0	9.0	86.0	0.2	32.5	6.0	3.5	10.0	1458	9
Banded Tulip Shell	6.0	1.0	2.5	0.0	42.5	104.5	0.2	5.5	27.5	1.0	24.0	131.5	3
Spiny Murex	9.0	76.0	1.0	0.0	58.5	937.5	0.2	11.0	7.0	8.0	43.0	1043	11
Spiny Murex (eggs)	30.0	2.0	1.0	44.5	22.5	132.5	0.3	6.5	5.0	8.5	10.5	298.5	1
Brown Soft Coral	240.0	3.5	11.5	9.0	10.0	337.5	0.3	23.5	18.0	7.5	594.0	251.5	3
Yellow Soft Coral	286.0	1.5	2.0	1.5	14.5	289.0	0.3	21.0	46.5	33.5	450.0	64.5	2
Hydroid	83.5	3.0	5.0	5.5	27.0	1303	0.3	66.5	16.5	10.0	247.5	129.0	3

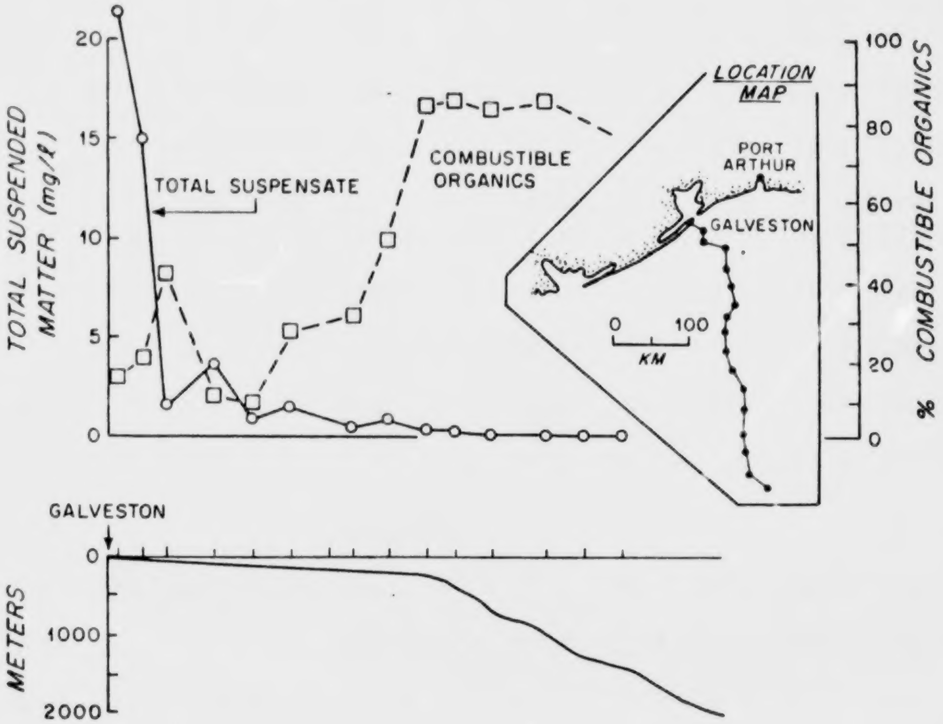


Figure 1: Suspended Sediment Sample Profile from Galveston Bay through the Buccaneer Field Area showing Boundary between Sediment Rich Galveston Bay Waters and Offshore Waters (from Manheim and others, 1972).

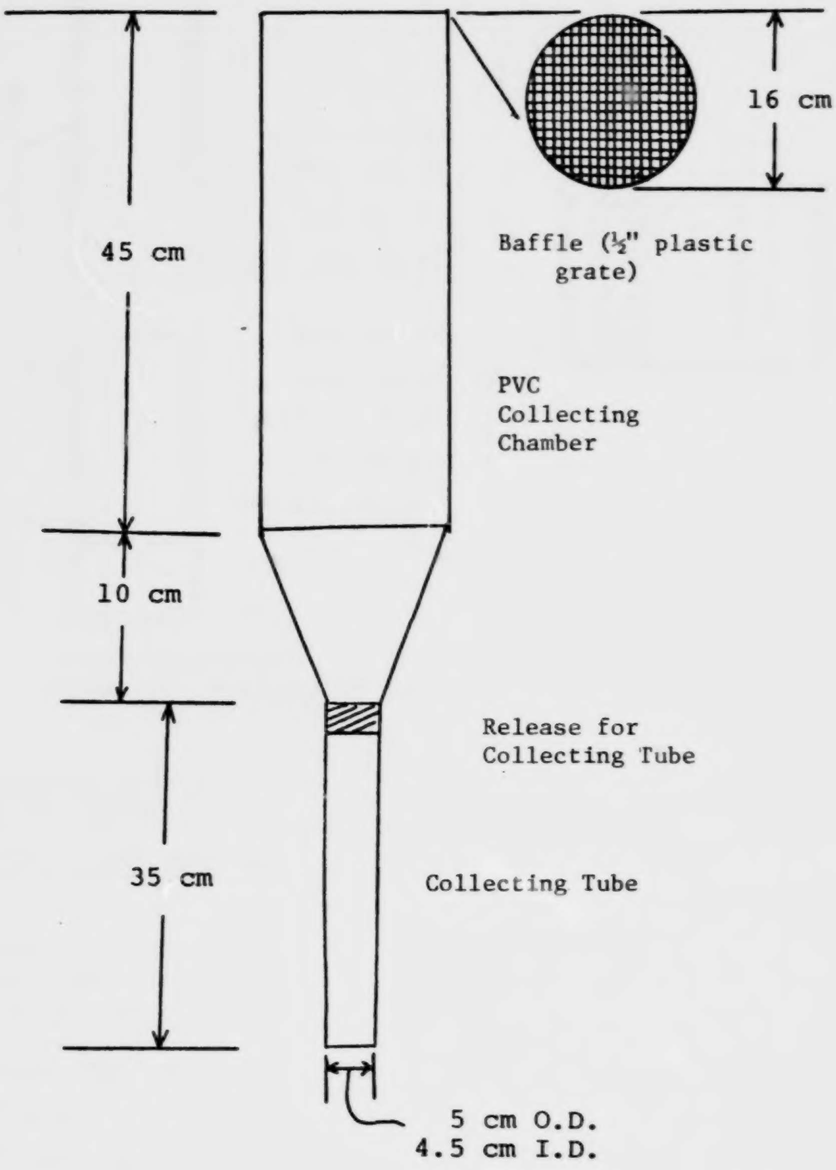

45 cm
10 cm
35 cm
16 cm
Baffle (½" plastic grate)
PVC Collecting Chamber
Release for Collecting Tube
Collecting Tube
5 cm O.D.
4.5 cm I.D.

FIGURE 2: DIAGRAM OF SEDIMENT TRAP USED IN THIS STUDY.

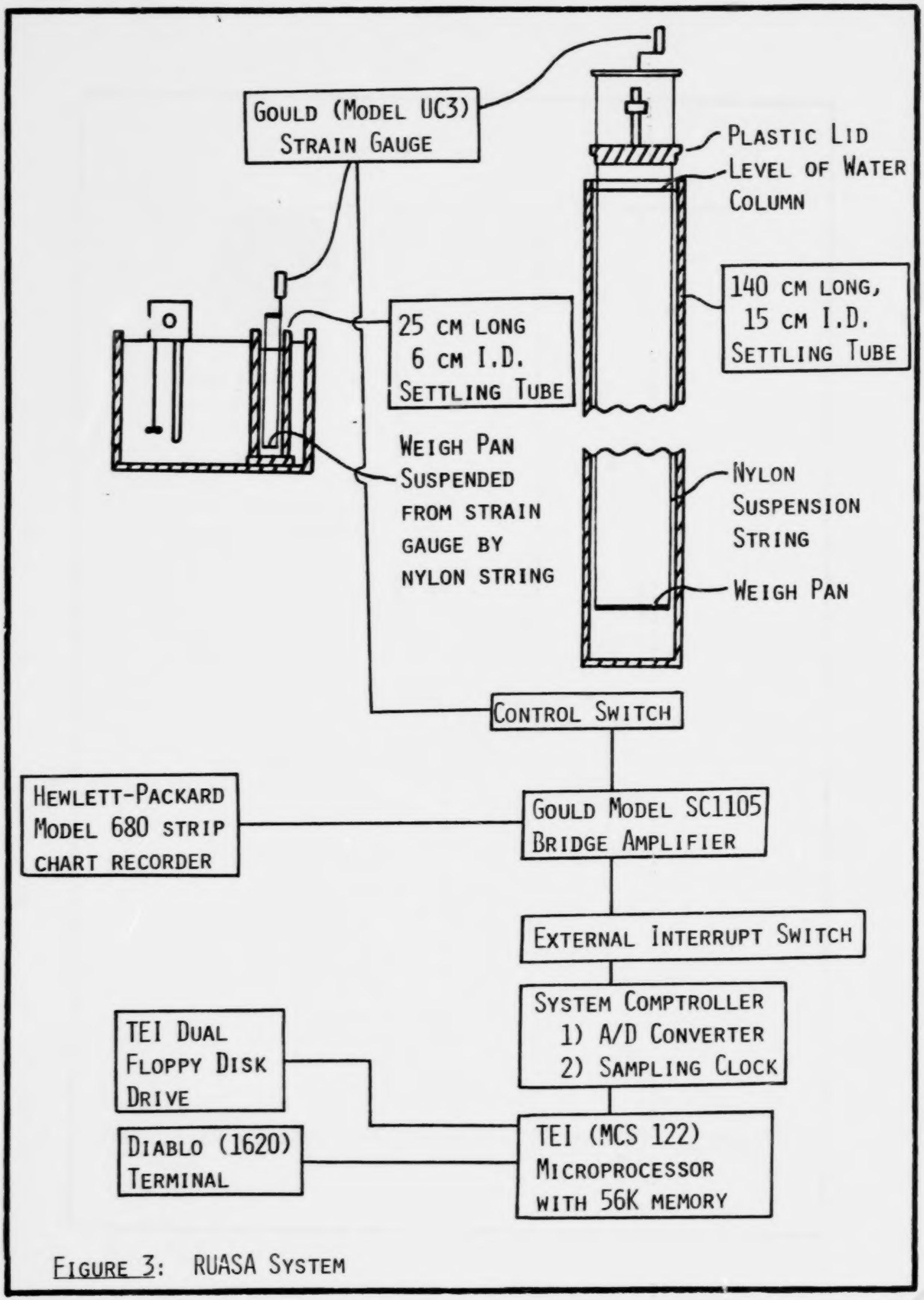

GOULD (MODEL UC3) STRAIN GAUGE
PLASTIC LID
LEVEL OF WATER COLUMN
140 CM LONG, 15 CM I.D. SETTLING TUBE
25 CM LONG 6 CM I.D. SETTLING TUBE
WEIGH PAN SUSPENDED FROM STRAIN GAUGE BY NYLON STRING
NYLON SUSPENSION STRING
WEIGH PAN
CONTROL SWITCH
HEWLETT-PACKARD MODEL 680 STRIP CHART RECORDER
GOULD MODEL SC1105 BRIDGE AMPLIFIER
EXTERNAL INTERRUPT SWITCH
SYSTEM COMPTROLLER
1) A/D CONVERTER
2) SAMPLING CLOCK
TEI DUAL FLOPPY DISK DRIVE
DIABLO (1620) TERMINAL
TEI (MCS 122) MICROPROCESSOR WITH 56K MEMORY

FIGURE 3: RUASA SYSTEM

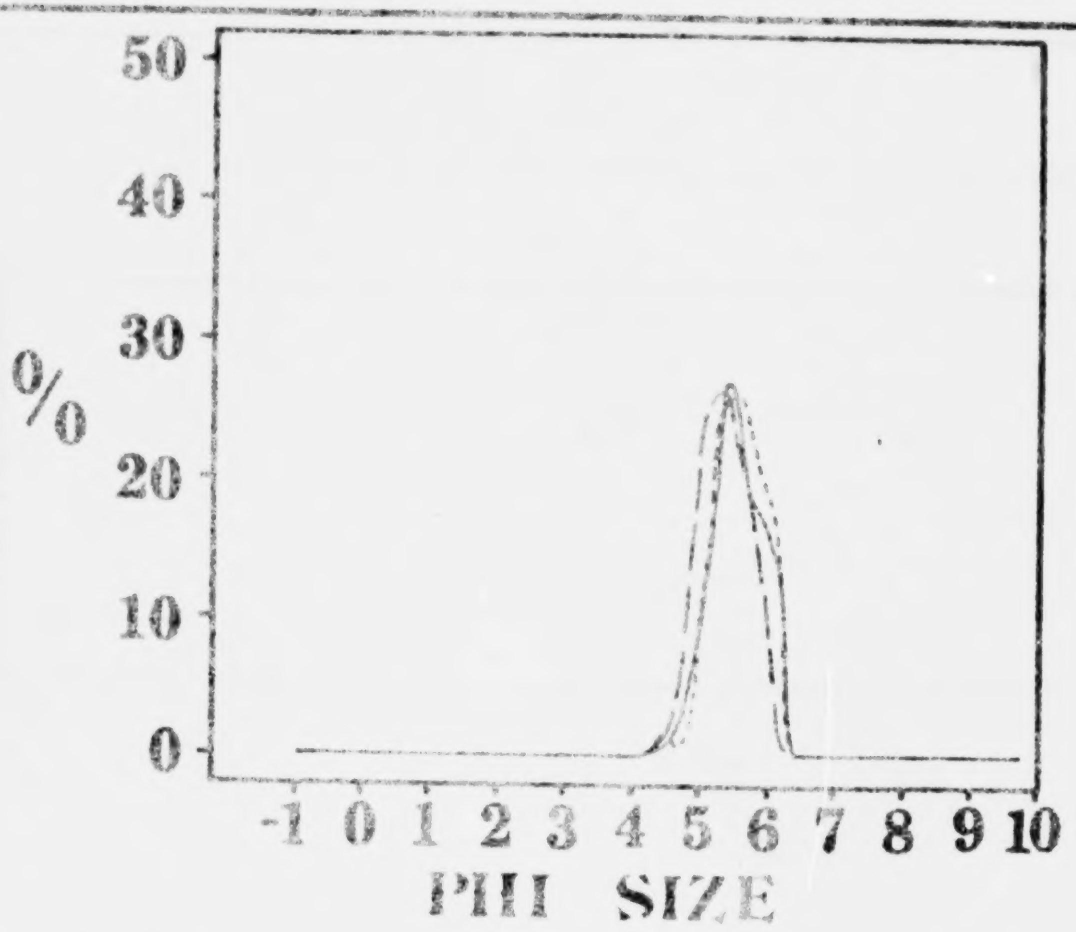


FIGURE 4: FREQUENCY CURVES FOR THE SAME SAMPLE ANALYSED THREE SEPARATE TIMES ON THE RUASA SYSTEM TO ILLUSTRATE REPRODUCIBILITY OF THE SYSTEM.

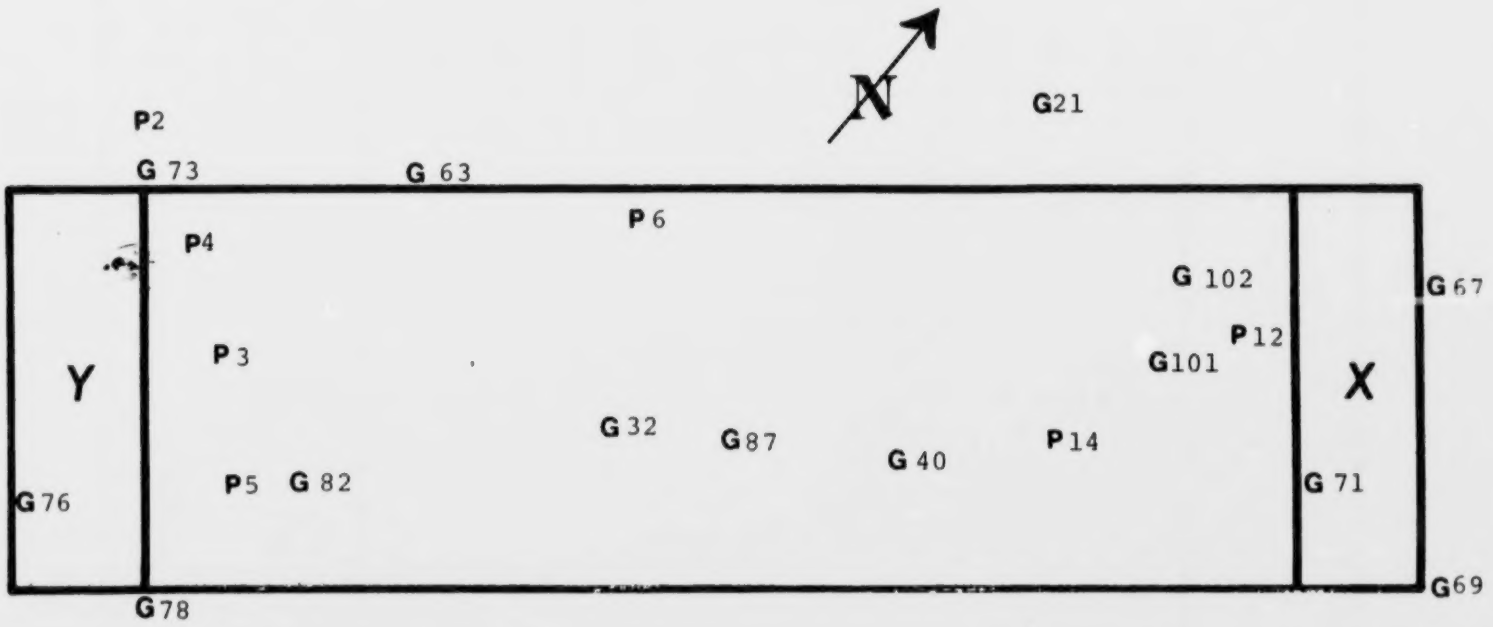

N
G21
P2
G 73
G 63
P 6
P4
G 102
G 67
P 12
G101
Y
P 3
X
G 32
G 87
G 40
P 14
P 5
G 82
G 76
G 71
G 78
G 69

Figure 5: Locations of Surficial Sediment Samples (labeled G) and Piston Cores (labeled P) from first year's sampling.

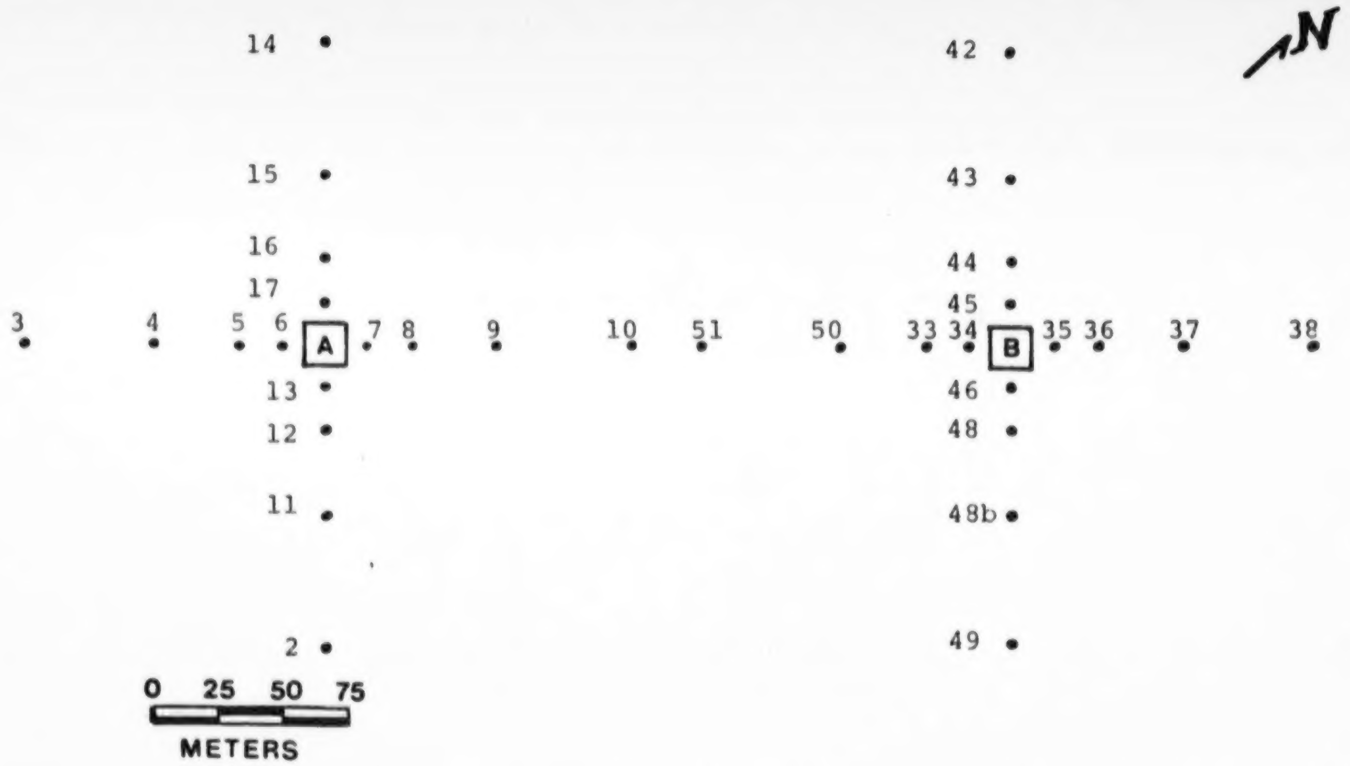

N
14
15
16
17
3
4
5
6
A
7
8
9
10
51
50
33
34
B
35
36
37
38
13
12
11
2
42
43
44
45
46
48
48b
49
0
25
50
75
METERS

Figure 6: Locations of surficial sediment samples near platforms A and B collected during the first year of the study.

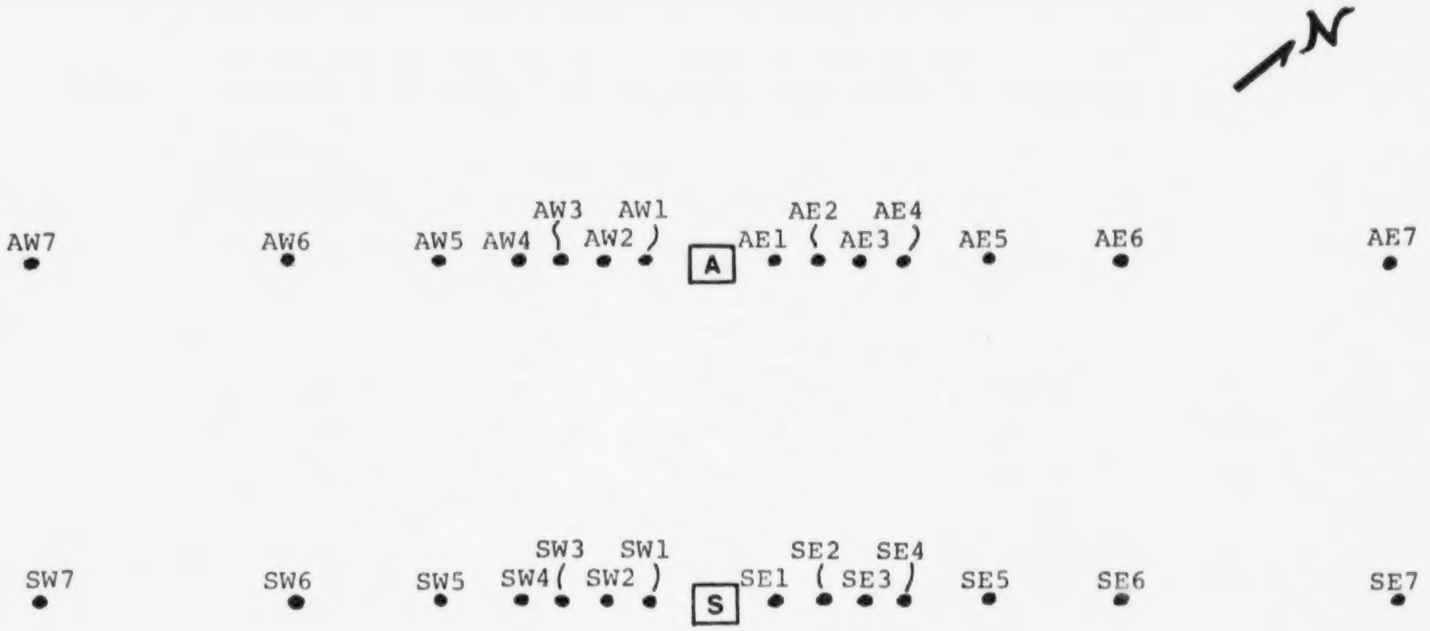

N
AW7
AW6
AW5
AW4
AW3
AW2
AW1
A
AE1
AE2
AE3
AE4
AE5
AE6
AE7
SW7
SW6
SW5
SW4
SW3
SW2
SW1
S
SE1
SE2
SE3
SE4
SE5
SE6
SE7

Figure 7: Locations of Diver Obtained Sediment Cores from around Platform 288-A and Satellite Structure 288-3.

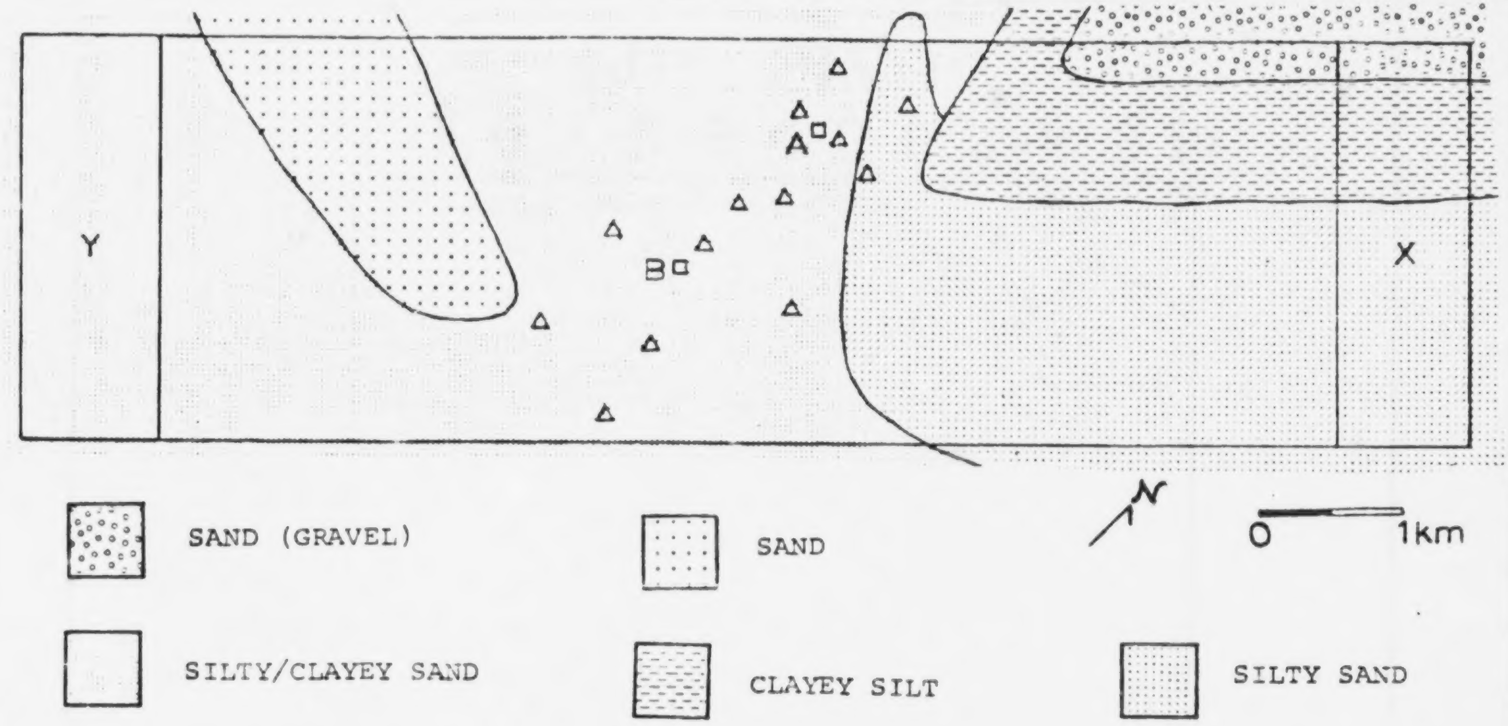

Y
A
B
X
SAND (GRAVEL)
SAND
SILTY/CLAYEY SAND
CLAYEY SILT
SILTY SAND
N
0
1km

Figure 8: Sediment Facies Map for Buccaneer Field Area Areas X and Y are original control areas for the study.

△ welljacket
A □ Platform 288-A
B □ Platform 296-B

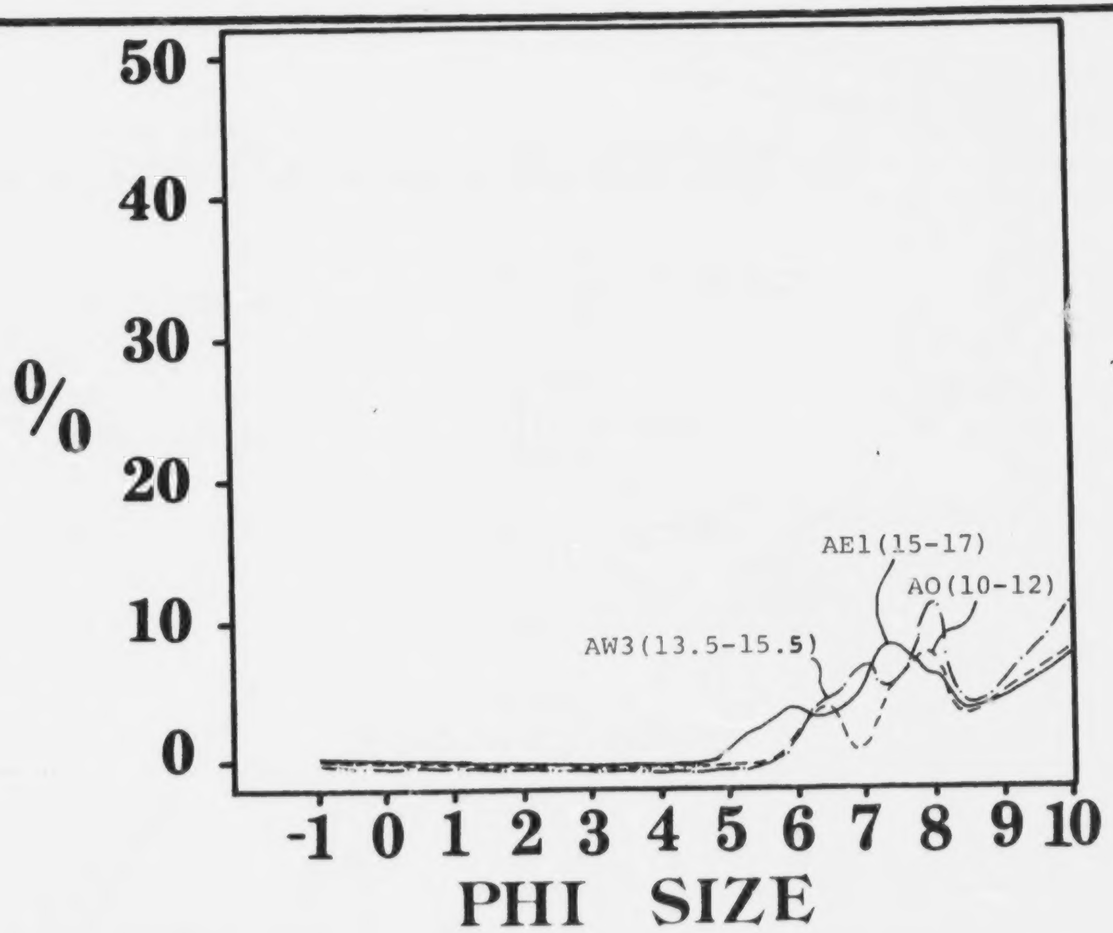


Figure 9: Representative Size Frequency Curves for Samples of the Beaumont Formation. See Table 1 for sample information.

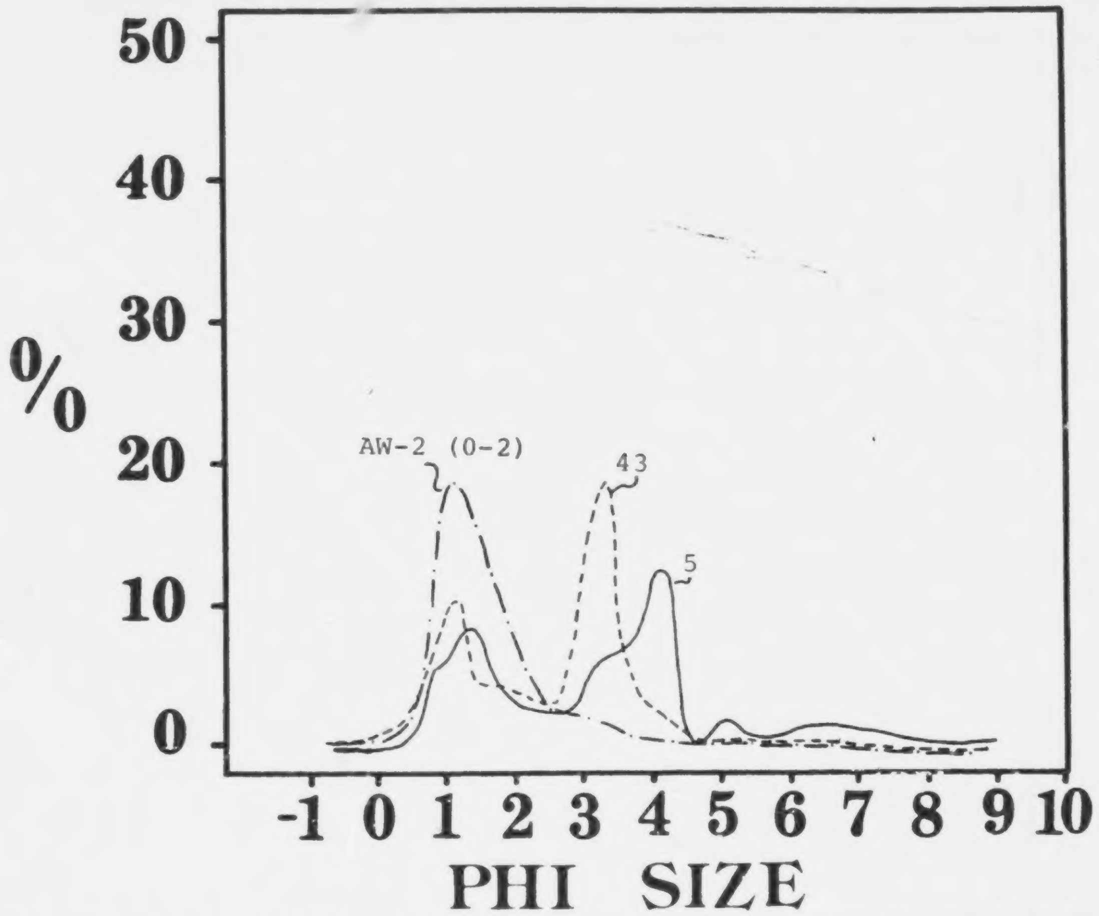


Figure 10: Representative Size Frequency Curves for Samples taken near Buccaneer Field Structures which Contain Relict Coarse (0.5Ø to 1.5Ø) sand unit. See Table 1 for sample information.

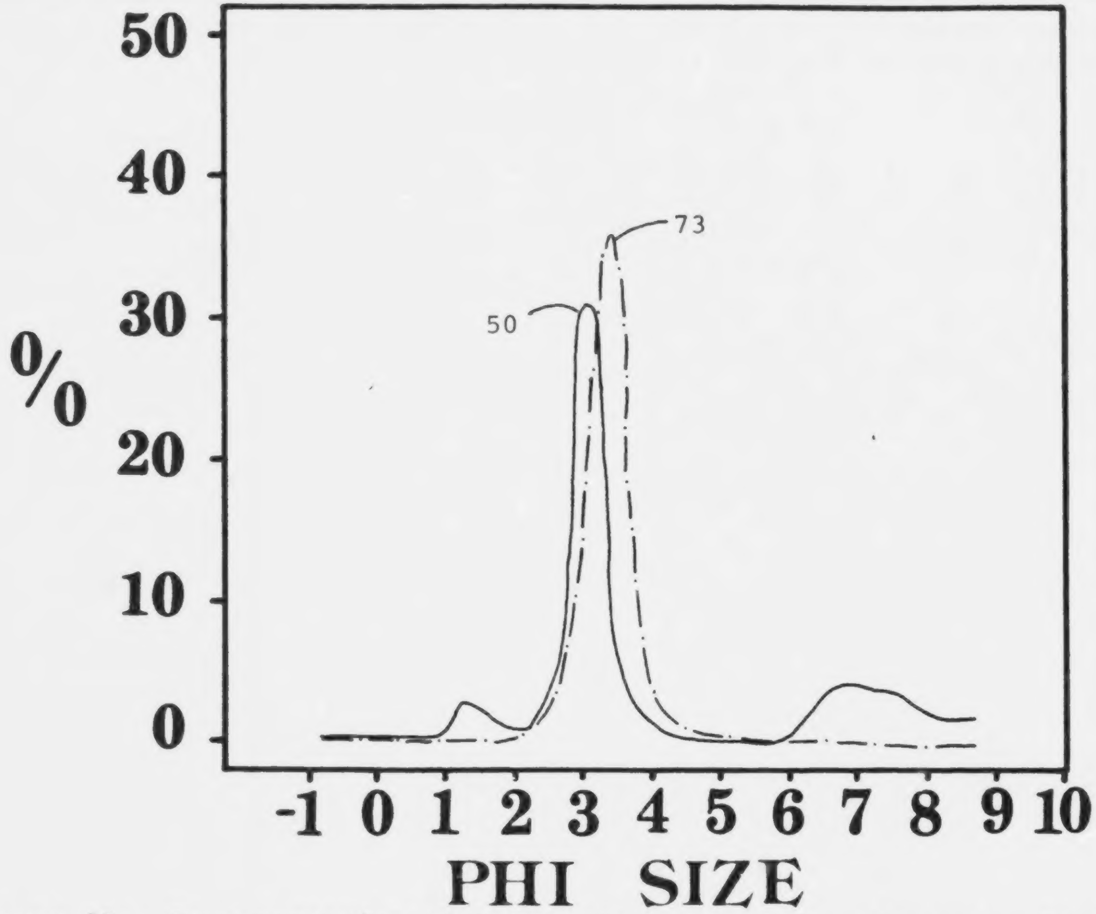


Figure 11: Representative Size Frequency Curves for Buccaneer Field Samples which Contain a Substantial, Fine Sand (3.5Ø) Component. See Table 1 for sample information.

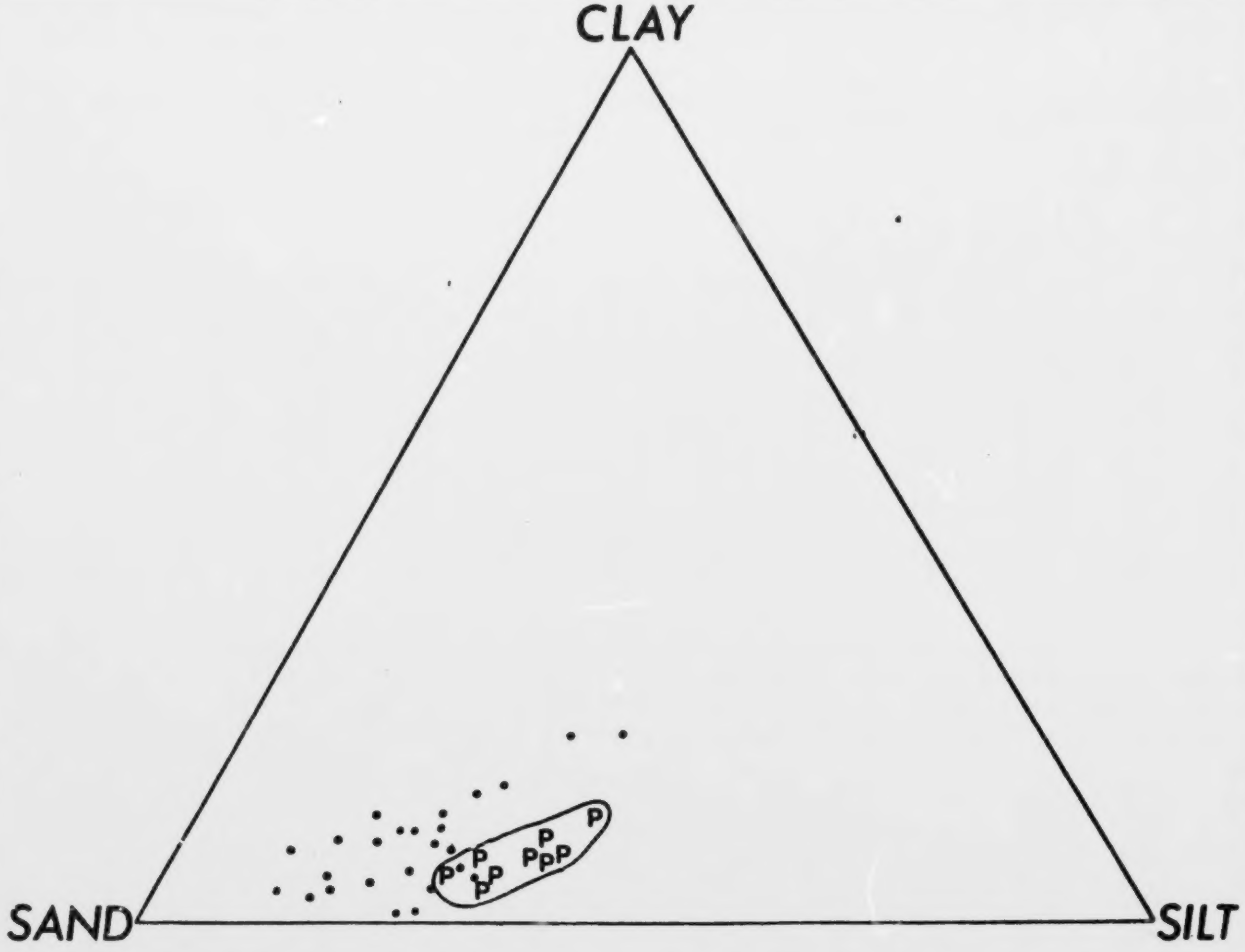
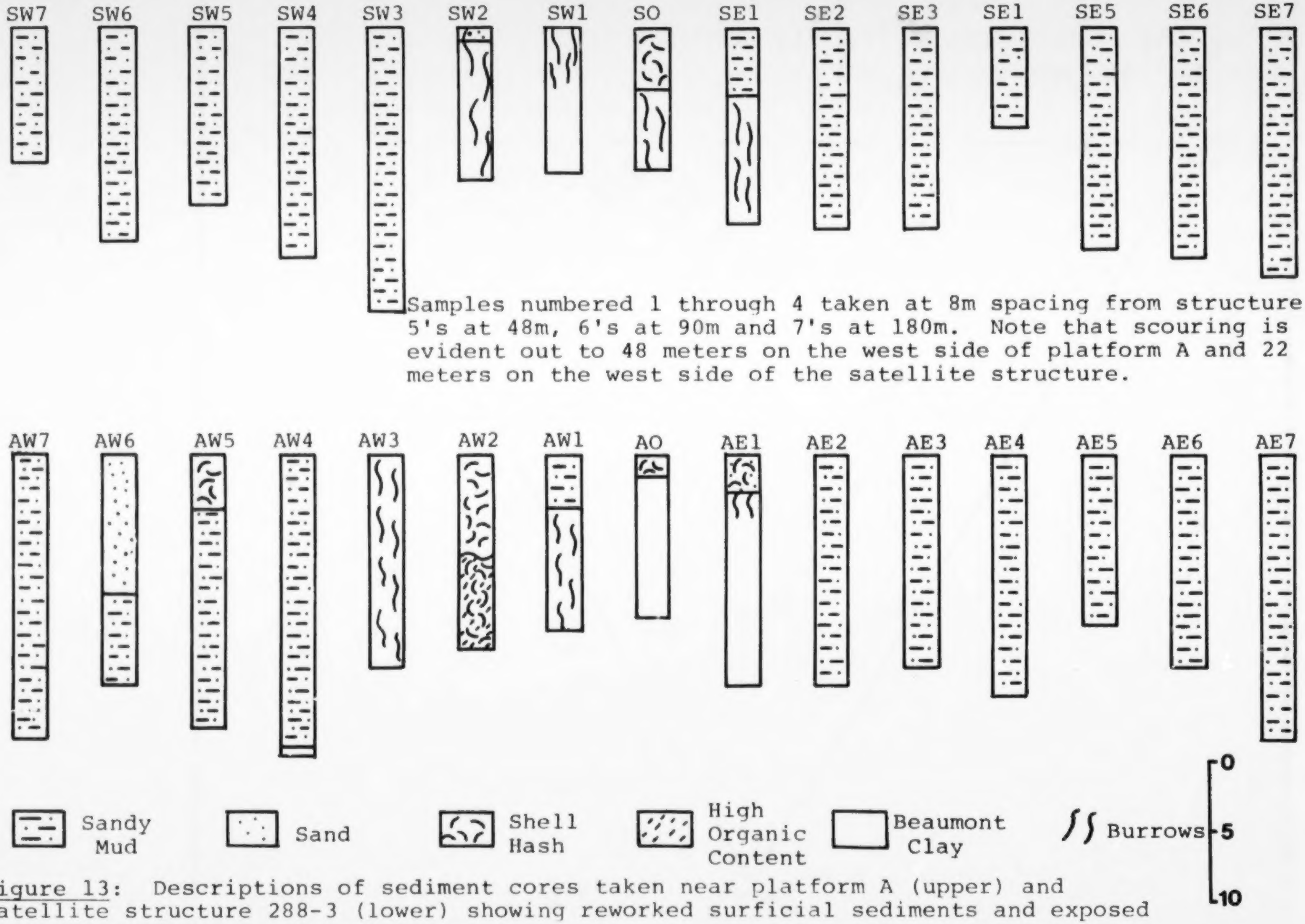


FIGURE 12: SAND/SILT/CLAY CONCENTRATIONS FOR SELECTED SURFICIAL SEDIMENTS FROM WITHIN THE BUCCANEER FIELD ALONG WITH SIMILAR DATA FOR SAMPLES TAKEN AT DEPTH FROM PISTON CORES.

These date, along with statistical data for all samples, are listed in Table 1.

]


SW7
SW6
SW5
SW4
SW3
SW2
SW1
SO
SE1
SE2
SE3
SE1
SE5
SE6
SE7
AW7
AW6
AW5
AW4
AW3
AW2
AW1
AO
AE1
AE2
AE3
AE4
AE5
AE6
AE7
Sandy Mud
Sand
Shell Hash
High Organic Content
Beaumont Clay
Burrows
0
5
10

Samples numbered 1 through 4 taken at 8m spacing from structure, 5's at 48m, 6's at 90m and 7's at 180m. Note that scouring is evident out to 48 meters on the west side of platform A and 22 meters on the west side of the satellite structure.

Figure 13: Descriptions of sediment cores taken near platform A (upper) and satellite structure 288-3 (lower) showing reworked surficial sediments and exposed Beaumont surface near structures.

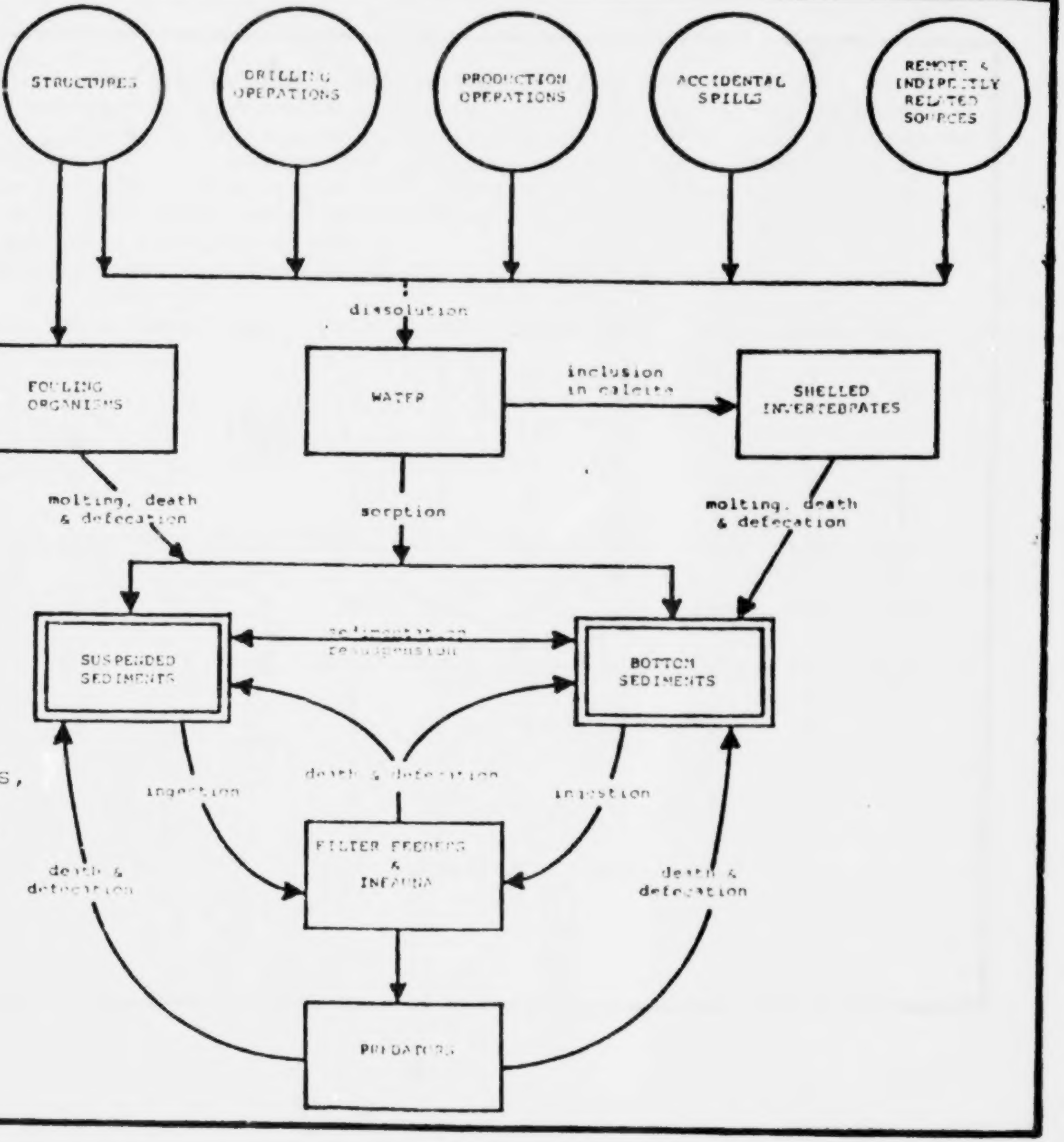

Sources
Intermediates
Sinks
STRUCTURES
DRILLING OPERATIONS
PRODUCTION OPERATIONS
ACCIDENTAL SPILLS
REMOTE & INDIRECTLY RELATED SOURCES
dissolution
FOULING ORGANISMS
WATER
inclusion in calcite
SHELLED INVERTEBRATES
molting, death & defecation
sorption
molting, death & defecation
SUSPENDED SEDIMENTS
sedimentation resuspension
BOTTOM SEDIMENTS
ingestion
death & defecation
ingestion
FILTER FEEDERS & INFAUNA
death & defecation
death & defecation
PREDATORS

Figure 14

Flow diagram showing sources, intermediates and sinks of contaminates in an offshore oil and gas field.

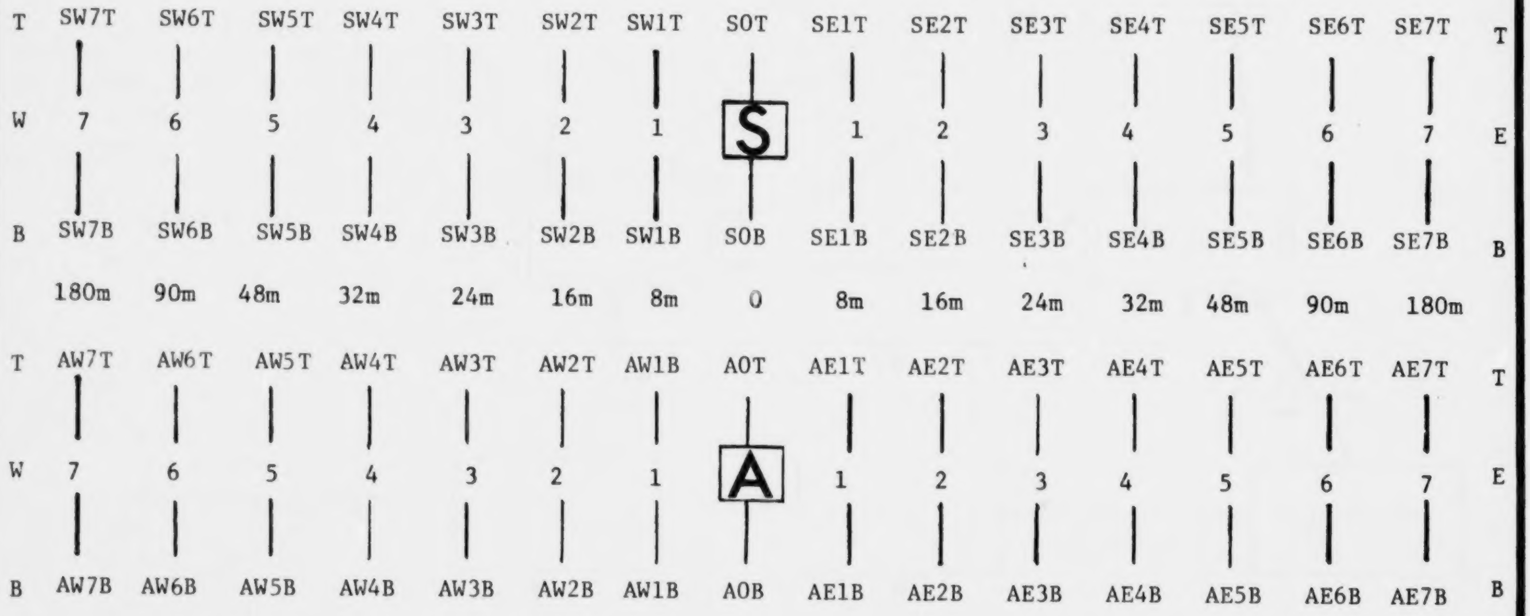
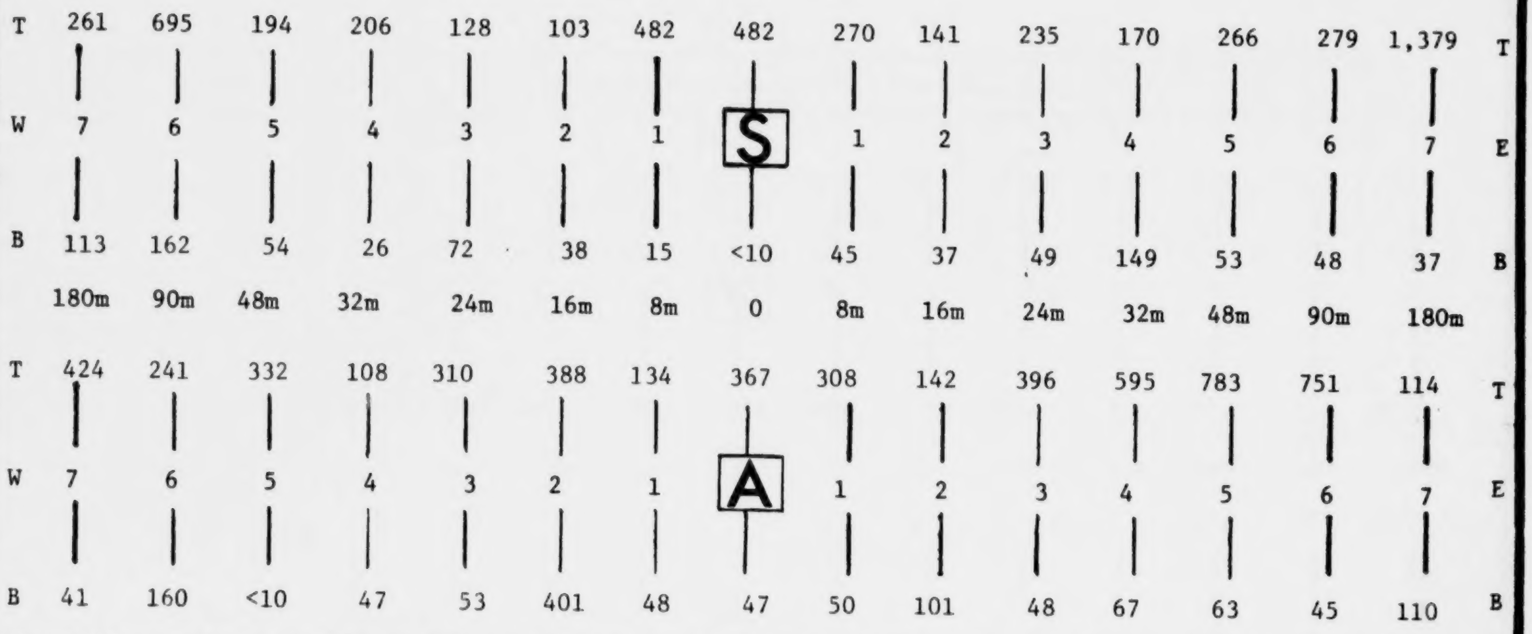

T SW7T SW6T SW5T SW4T SW3T SW2T SW1T SOT SE1T SE2T SE3T SE4T SE5T SE6T SE7T T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B SW7B SW6B SW5B SW4B SW3B SW2B SW1B SOB SE1B SE2B SE3B SE4B SE5B SE6B SE7B B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T AW7T AW6T AW5T AW4T AW3T AW2T AW1B AOT AE1T AE2T AE3T AE4T AE5T AE6T AE7T T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B AW7B AW6B AW5B AW4B AW3B AW2B AW1B AOB AE1B AE2B AE3B AE4B AE5B AE6B AE7B B

Figure 15. Location of Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

The diver obtained sediment cores were collected at distances of 8. 16, 24, 32, 48, 90 and 180 meters along E-W transects from platform 288-A and satellite structure S (288-3). The top 1-2 cm and the bottom 1-2 cm of each core was analyzed for trace metals (see Table 7). Station abbreviations are as follows: A (platform 288-A), S (satellite structure 288-S), W(West), E(East), T(top of core) and B(bottom of core). The numbers 1 through 7 denote locations at distances of 8, 16, 24, 32, 48, 90 and 180 meters from the structures respectively. The zero sample number denotes samples taken directly below the structures.



T	261	695	194	206	128	103	482	482	270	141	235	170	266	279	1,379	T
W	7	6	5	4	3	2	1	S	1	2	3	4	5	6	7	E
B	113	162	54	26	72	38	15	<10	45	37	49	149	53	48	37	B
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m	
T	424	241	332	108	310	388	134	367	308	142	396	595	783	751	114	T
W	7	6	5	4	3	2	1	A	1	2	3	4	5	6	7	E
B	41	160	<10	47	53	401	48	47	50	101	48	67	63	45	110	B

Figure 16a. Geographic Distribution of Ba in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 15 except that sample numbers have been replaced with the appropriate Ba concentration in ppm. All abbreviations are the same as in Figure 15. For example, the Ba concentration of the top 1 to 2 cm of sample number SE3T is 235 ppm.

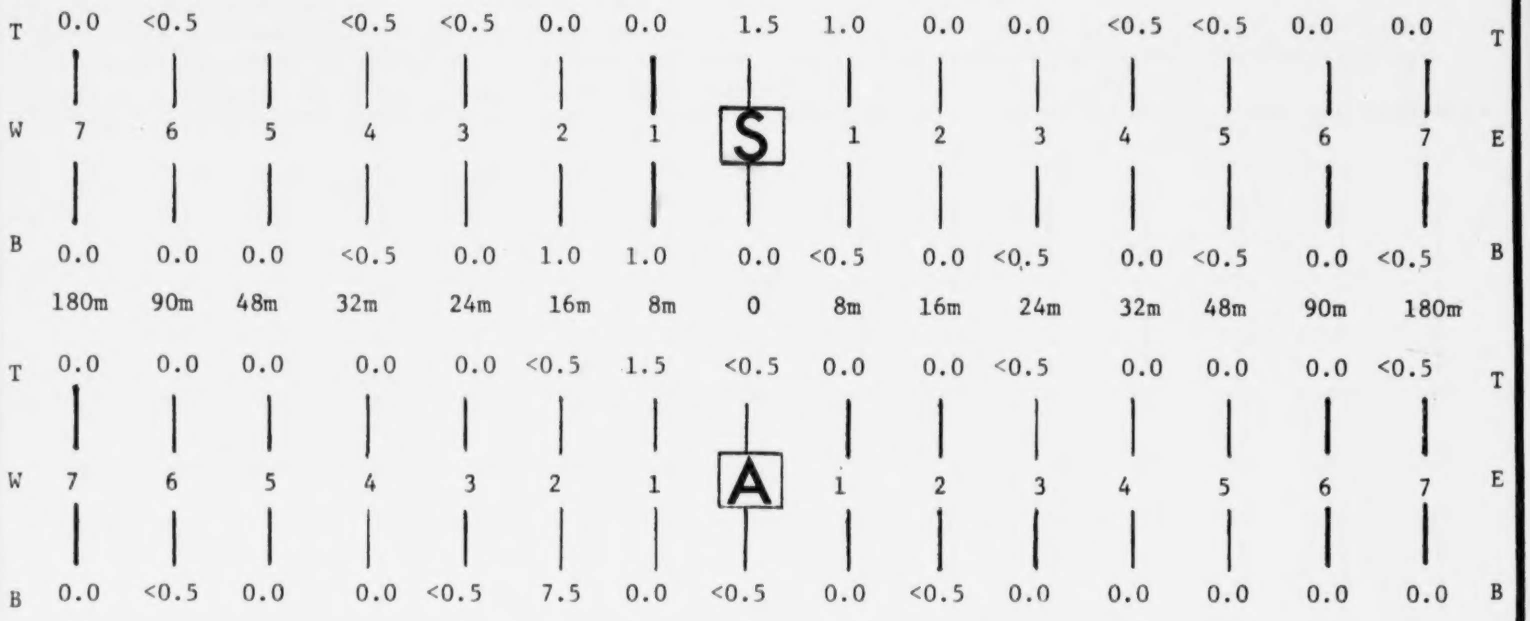

T 0.0 <0.5 <0.5 <0.5 0.0 0.0 1.5 1.0 0.0 0.0 <0.5 <0.5 0.0 0.0 T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B 0.0 0.0 0.0 <0.5 0.0 1.0 1.0 0.0 <0.5 0.0 <0.5 0.0 <0.5 0.0 <0.5 B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T 0.0 0.0 0.0 0.0 0.0 <0.5 1.5 <0.5 0.0 0.0 <0.5 0.0 0.0 0.0 <0.5 T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B 0.0 <0.5 0.0 0.0 <0.5 7.5 0.0 <0.5 0.0 <0.5 0.0 0.0 0.0 0.0 0.0 B

Figure 16b. Geographic Distribution of Cd in Diver Otained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Cd in ppm.

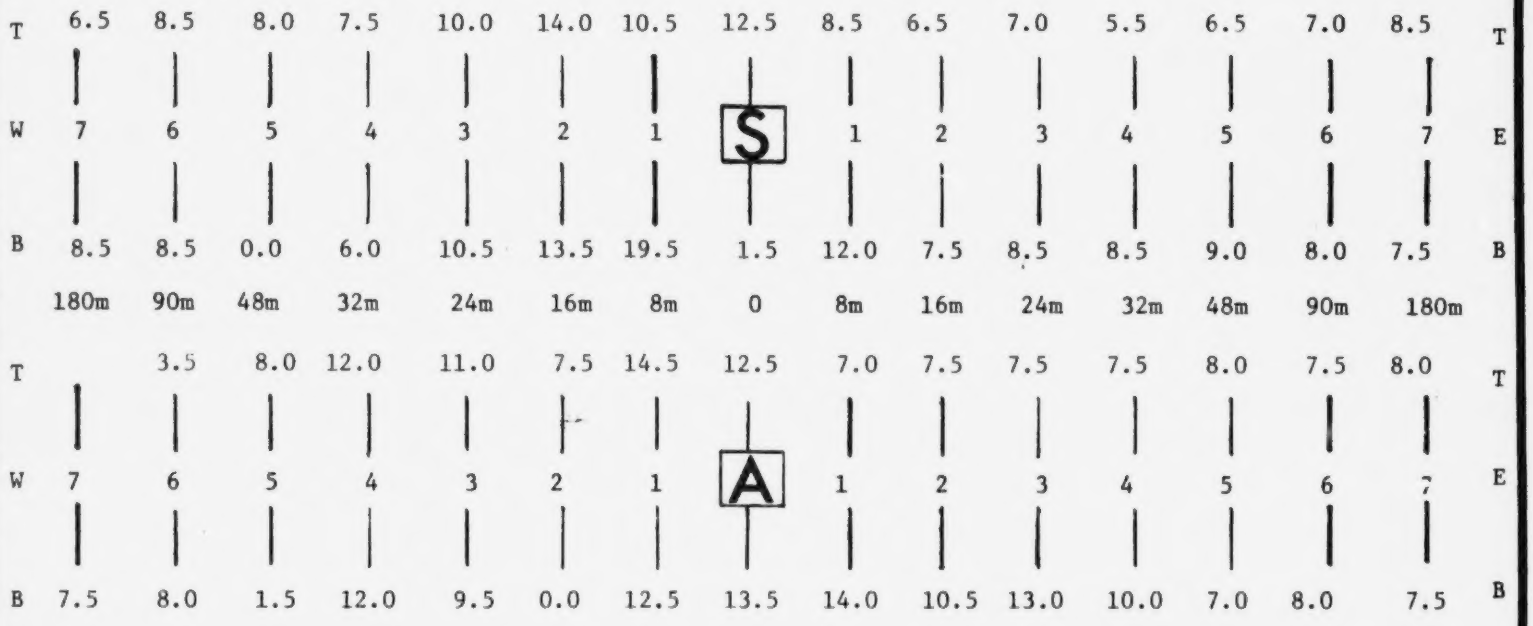

T 6.5 8.5 8.0 7.5 10.0 14.0 10.5 12.5 8.5 6.5 7.0 5.5 6.5 7.0 8.5 T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B 8.5 8.5 0.0 6.0 10.5 13.5 19.5 1.5 12.0 7.5 8.5 8.5 9.0 8.0 7.5 B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T 3.5 8.0 12.0 11.0 7.5 14.5 12.5 7.0 7.5 7.5 7.5 8.0 7.5 8.0 T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B 7.5 8.0 1.5 12.0 9.5 0.0 12.5 13.5 14.0 10.5 13.0 10.0 7.0 8.0 7.5 B

Figure 16c. Geographic Distribution of Co in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Co in ppm.

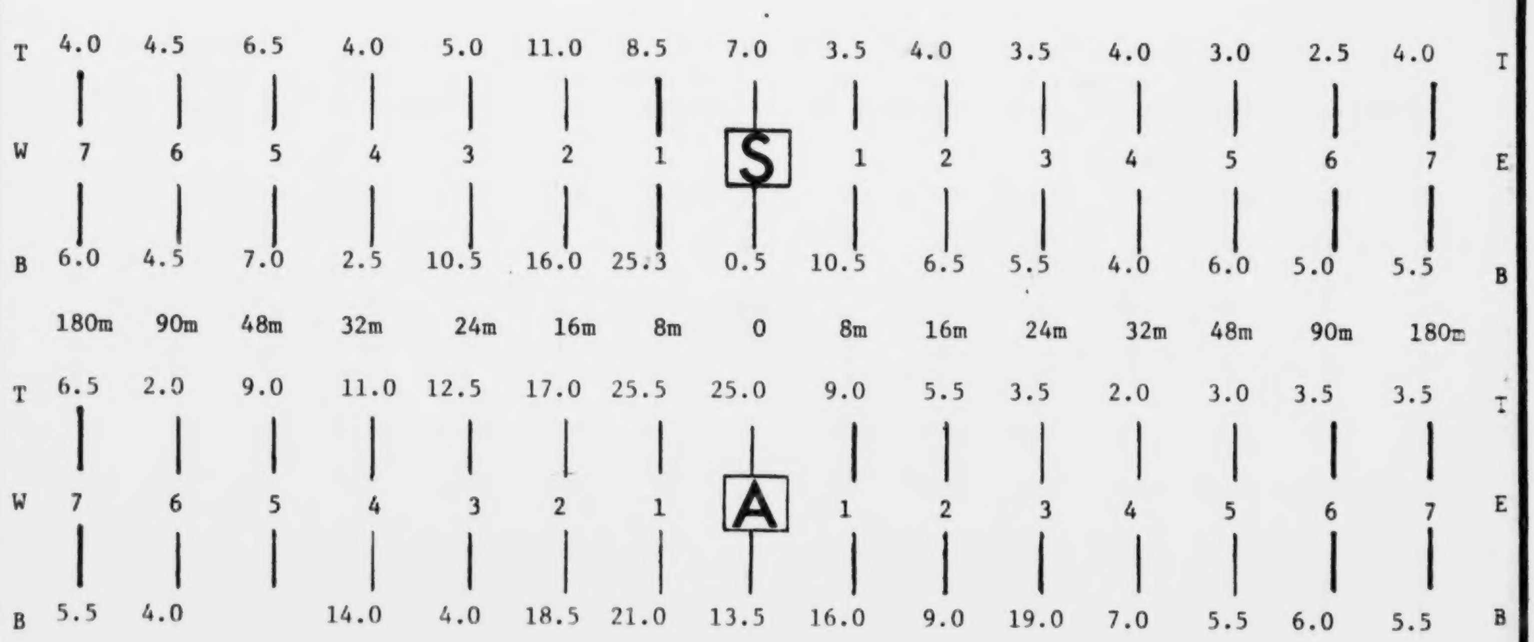

T 4.0 4.5 6.5 4.0 5.0 11.0 8.5 7.0 3.5 4.0 3.5 4.0 3.0 2.5 4.0 T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B 6.0 4.5 7.0 2.5 10.5 16.0 25.3 0.5 10.5 6.5 5.5 4.0 6.0 5.0 5.5 B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T 6.5 2.0 9.0 11.0 12.5 17.0 25.5 25.0 9.0 5.5 3.5 2.0 3.0 3.5 3.5 T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B 5.5 4.0 14.0 4.0 18.5 21.0 13.5 16.0 9.0 19.0 7.0 5.5 6.0 5.5 B

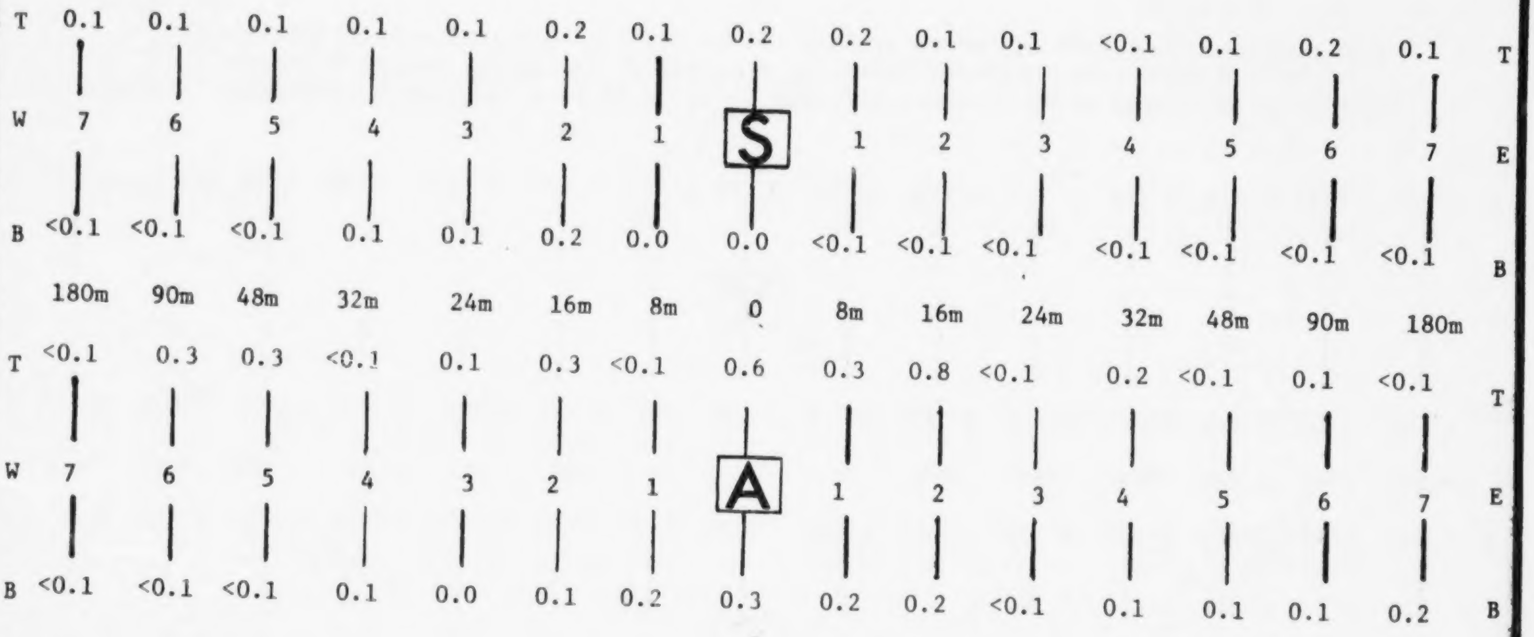
Figure 16e. Geographic Distribution of Cu in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Cu in ppm.

T	0.82	.96	1.20	1.18	1.20	1.57	2.19	1.64	.73	.91	.88	.77	0.80	.63	.84	T
W	7	6	5	4	3	2	1	S	1	2	3	4	5	6	7	E
B	1.22	1.05	.92	1.01	2.61	2.44	.89		1.69	1.36	1.11	1.02	1.15	1.14	1.09	B
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m	
T	.85	.41	1.07	1.88	1.95	1.43			.98	1.29	.84	.67	.59	.77	.88	T
W	7	6	5	4	3	2	1	A	1	2	3	4	5	6	7	E
B	1.05	.96		1.88	.92	1.19	2.13			1.29	2.27	1.43	1.06	1.05	1.10	B

Figure 16f. Geographic Distribution of Fe in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite STructure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Fe in %.



	W 7	6	5	4	3	2	1	S	1	2	3	4	5	6	7 E
T	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	<0.1	0.1	0.2	0.1
B	<0.1	<0.1	<0.1	0.1	0.1	0.2	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m

	W 7	6	5	4	3	2	1	A	1	2	3	4	5	6	7 E
T	<0.1	0.3	0.3	<0.1	0.1	0.3	<0.1	0.6	0.3	0.8	<0.1	0.2	<0.1	0.1	<0.1
B	<0.1	<0.1	<0.1	0.1	0.0	0.1	0.2	0.3	0.2	0.2	<0.1	0.1	0.1	0.1	0.2

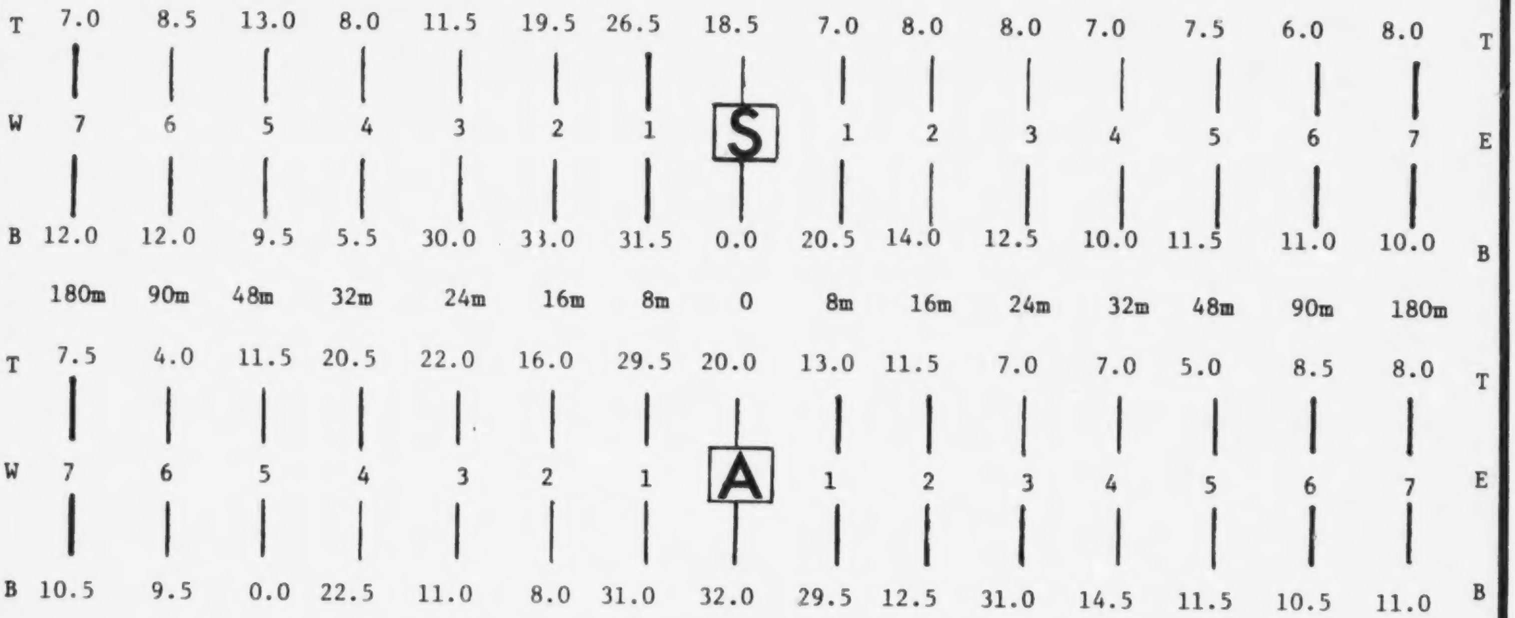
Figure 16g. Geographic Distribution of Hg in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Hg in ppm.

T	220.0	205.5	231.5	193.5	219.5	369.0	223.0	187.0	187.0	247.5	212.0	150.0	191.5	183.5	257.5	T
W	7	6	5	4	3	2	1	S	1	2	3	4	5	6	7	E
B	194.0	178.5	231.0	156.0	256.0	220.5	108.5	54.0	189.5	158.5	207.0	218.0	196.5	188.0	164.0	B
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m	
T	204.5	120.5	231.0	247.0	240.0	254.5	275.0	293.5	171.5	237.0	167.0	192.5	162.0	191.0	209.5	T
W	7	6	5	4	3	2	1	A	1	2	3	4	5	6	7	E
B	187.0	171.0	0.0	162.5	175.5	197.5	155.0	207.0	200.5	243.5	144.5	222.0	187.5	221.5	200.5	B

Figure 16h. Geographic Distribution of Mn in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3)

This diagram is identical to Figure 16a except that it shows the geographic distribution of Mn in ppm.



	W 7	6	5	4	3	2	1	S	1	2	3	4	5	6	7 E
T	7.0	8.5	13.0	8.0	11.5	19.5	26.5	18.5	7.0	8.0	8.0	7.0	7.5	6.0	8.0
B	12.0	12.0	9.5	5.5	30.0	33.0	31.5	0.0	20.5	14.0	12.5	10.0	11.5	11.0	10.0
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m

	W 7	6	5	4	3	2	1	A	1	2	3	4	5	6	7 E
T	7.5	4.0	11.5	20.5	22.0	16.0	29.5	20.0	13.0	11.5	7.0	7.0	5.0	8.5	8.0
B	10.5	9.5	0.0	22.5	11.0	8.0	31.0	32.0	29.5	12.5	31.0	14.5	11.5	10.5	11.0

Figure 16i. Geographic Distribution of Ni in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3). This diagram is identical to Figure 16a except that it shows the geographic distribution of Ni in ppm.

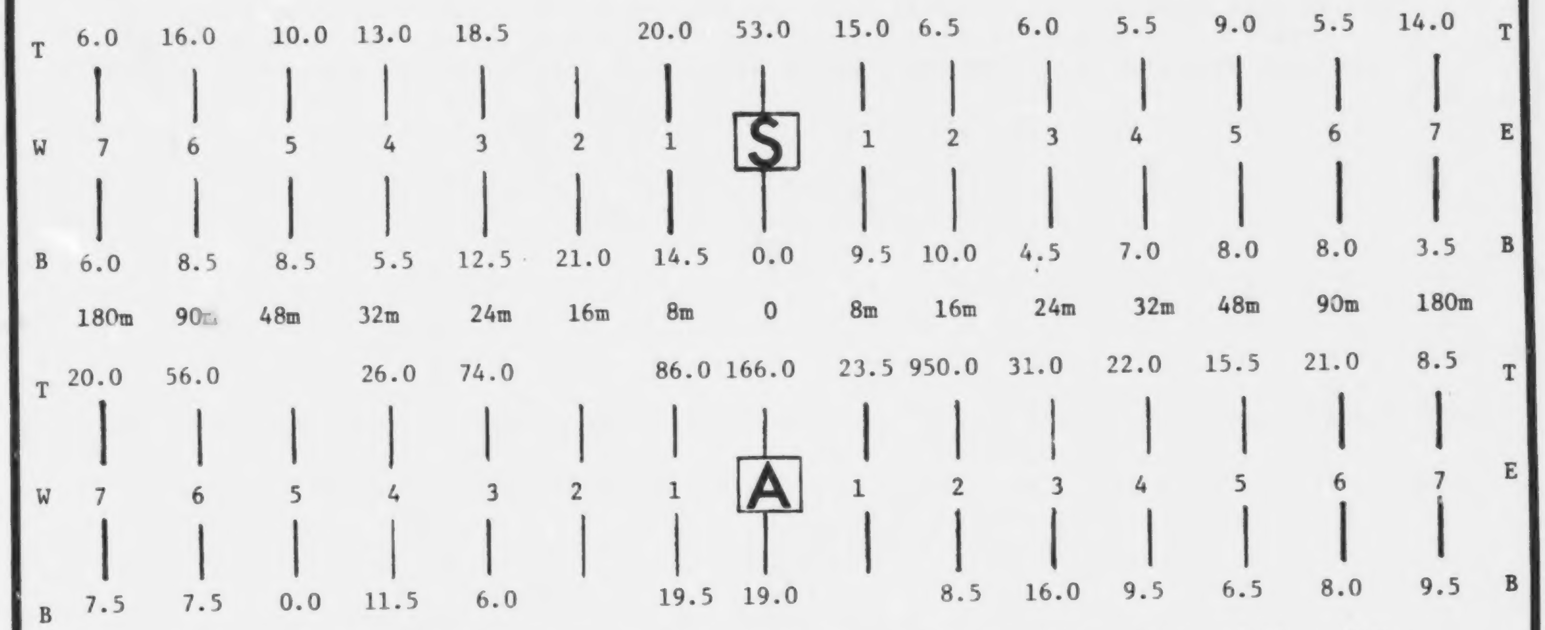

T 6.0 16.0 10.0 13.0 18.5 20.0 53.0 15.0 6.5 6.0 5.5 9.0 5.5 14.0 T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B 6.0 8.5 8.5 5.5 12.5 21.0 14.5 0.0 9.5 10.0 4.5 7.0 8.0 8.0 3.5 B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T 20.0 56.0 26.0 74.0 86.0 166.0 23.5 950.0 31.0 22.0 15.5 21.0 8.5 T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B 7.5 7.5 0.0 11.5 6.0 19.5 19.0 8.5 16.0 9.5 6.5 8.0 9.5 B

Figure 16j. Geographic Distribution of Pb in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Pb in ppm.

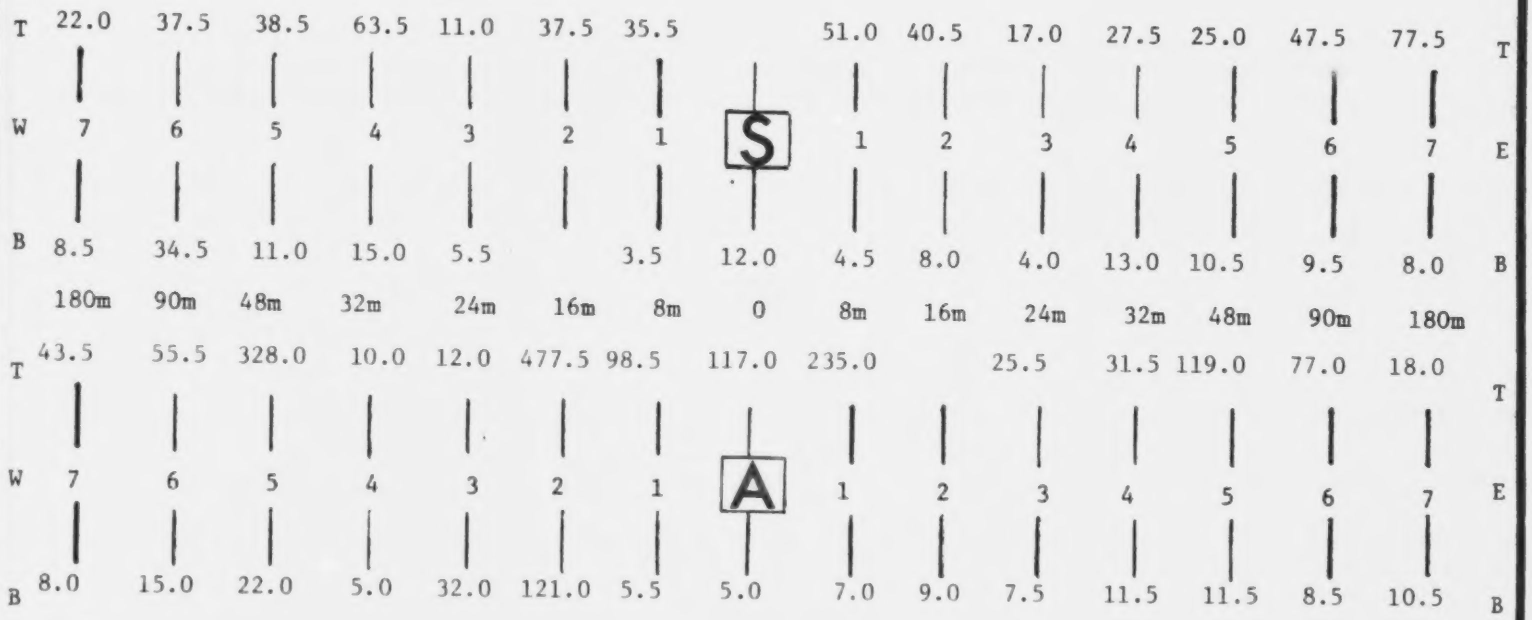
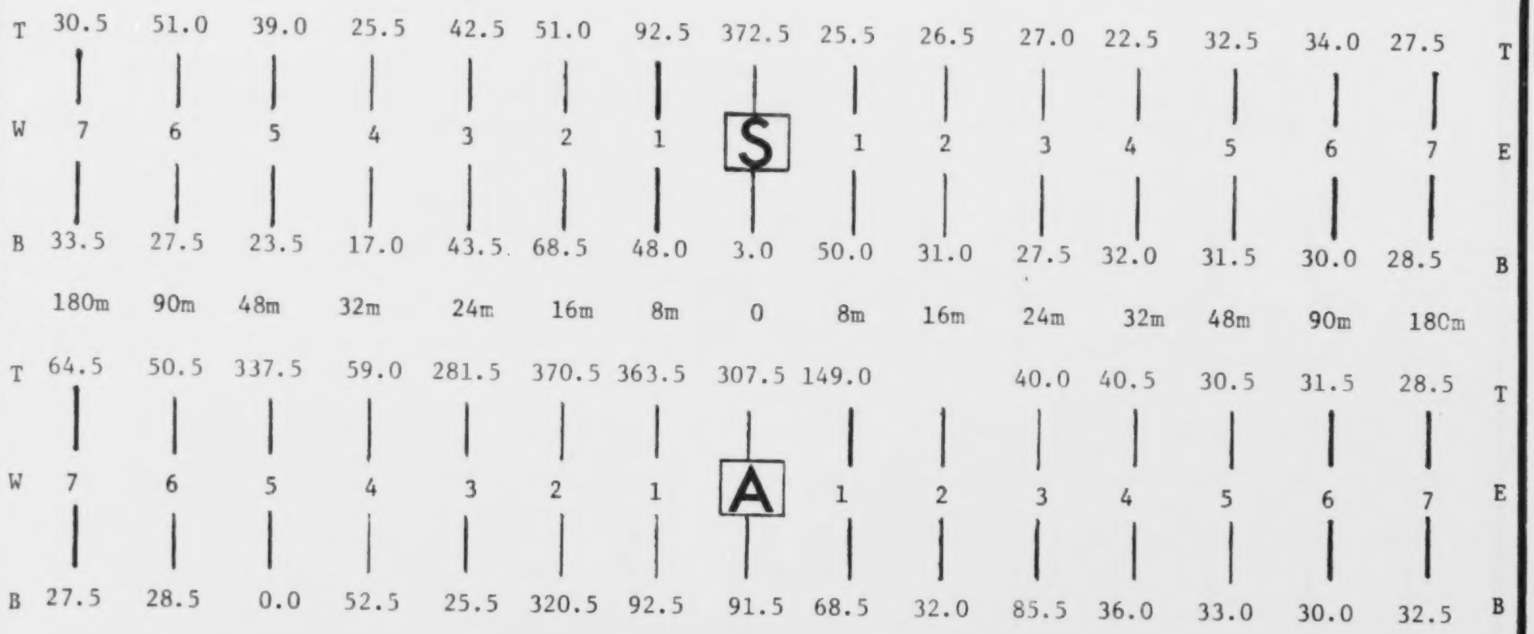

T 22.0 37.5 38.5 63.5 11.0 37.5 35.5 51.0 40.5 17.0 27.5 25.0 47.5 77.5 T
W 7 6 5 4 3 2 1 S 1 2 3 4 5 6 7 E
B 8.5 34.5 11.0 15.0 5.5 3.5 12.0 4.5 8.0 4.0 13.0 10.5 9.5 8.0 B
180m 90m 48m 32m 24m 16m 8m 0 8m 16m 24m 32m 48m 90m 180m
T 43.5 55.5 328.0 10.0 12.0 477.5 98.5 117.0 235.0 25.5 31.5 119.0 77.0 18.0 T
W 7 6 5 4 3 2 1 A 1 2 3 4 5 6 7 E
B 8.0 15.0 22.0 5.0 32.0 121.0 5.5 5.0 7.0 9.0 7.5 11.5 11.5 8.5 10.5 B

Figure 16k. Geographic Distribution of Sr in Diver Obtained Sediment Cores Collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Sr in ppm.



	W 7	6	5	4	3	2	1	S	1	2	3	4	5	6	7 E
T	30.5	51.0	39.0	25.5	42.5	51.0	92.5	372.5	25.5	26.5	27.0	22.5	32.5	34.0	27.5
B	33.5	27.5	23.5	17.0	43.5	68.5	48.0	3.0	50.0	31.0	27.5	32.0	31.5	30.0	28.5
	180m	90m	48m	32m	24m	16m	8m	0	8m	16m	24m	32m	48m	90m	180m

	W 7	6	5	4	3	2	1	A	1	2	3	4	5	6	7 E
T	64.5	50.5	337.5	59.0	281.5	370.5	363.5	307.5	149.0		40.0	40.5	30.5	31.5	28.5
B	27.5	28.5	0.0	52.5	25.5	320.5	92.5	91.5	68.5	32.0	85.5	36.0	33.0	30.0	32.5

Figure 16ℓ. Geographic Distribution of Zn in Diver Obtained Sediment Cores collected Along E-W Transects Within 180 Meters of Platform 288-A and Satellite Structure S (288-3).

This diagram is identical to Figure 16a except that it shows the geographic distribution of Zn in ppm.

Work Unit 2.3.9 Describe Seasonal Circulation Patterns in the Oil Field

Part A

NMFS Atlantic Environmental Group
Narragansett Laboratory
R. S. Armstrong

Part B

Evans-Hamilton, Incorporated
Southern Region
R. C. Hamilton

ABSTRACT

Three seasonal dye diffusion experiments were conducted and Eulerian and Lagrangian current measurements and wind observations were analyzed during the second year of effort in the Currents and Hydrography Work Unit. Dye studies indicated that rates of dispersion of dissolved and suspended materials are controlled by winds, currents and tides. Rates of spread along principal axes and in area, as measured by equivalent radius, increase linearly with time, but diminished rate of increase in areal coverage occurs during slack tide periods. Dye plumes grew more rapidly in downwind directions and with the current trajectory. Growth rates also seemed to be highly dependent on vertical shear of horizontal flow. Transport of the dye plumes was governed by the currents, aided or diminished by tidal currents.

Currents were found to be aligned principally in alongshore directions, reversing seasonally from upcoast toward the northeast in summer (May-August) to downcoast toward southwest for October-April. Transitional conditions seemed to rule in September and April. Transponding buoys indicated little or no vertical structure to the currents, but current meter records showed layering of contrasting flows during summer. Local winds were apparently the main driving force for the circulation, with flow typically with the wind, deflected by the coastline and with compensating offshore transport with onshore winds, or to the right of the winds as with Ekman transport. Distinct departures from local wind-driven circulation develop during spring, when it seems high river discharge may establish a downcoast, geostrophic current which, from current meter records, may account for the layered currents of summer. Also, during early fall currents of the area do not seem to relate to local winds, but may be responding to larger scale atmospheric alterations. Spectral analyses of current meter records indicate that tidal currents and wind shifts account for most of the variability in flow dynamics, with dominant periods perhaps associated with passage of continental air masses in winter and fall and longer period maritime air mass development during summer.

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INTRODUCTION

The concentration, distribution, and movement of potential contaminants in the marine environment that may result from petroleum operations are determined by the currents, hydrographic structure, and diffusive mixing processes, as well as the nature and character of the pollutant.

The purposes of this second year's effort in investigating the currents and hydrography of the Buccaneer Field have been to:

1) define the annual circulation pattern and forces governing the currents

2) describe dispersion characteristics of the waters

3) develop information for predictive modelling of concentration and movement of potential contaminants

4) provide physical oceanographic interpretations supportive of other projects.

For the concerns of dispersion and transport, potential contaminants can be considered to consist of three basic types: those that float on the surface as a film, those that occur in the water column in dissolved form, and those adsorbed onto suspended particulate matter (including materials that initially sink to the bottom and later go into solution or re-suspension). This second year's effort was focused on the types that would be dissolved or suspended in the water column. A review and assessment of methods and results for predicting surface film (oil spill) movement and spread has been prepared by Rath and Francis (1977).

Background

During the first year, research was directed toward obtaining data for description of the annual cycles of currents and hydrographic conditions (temperature and salinity). Surface and subsurface currents were determined from land-based tracking of drifting, transponding buoys drogued to 1-m and 10- to 18-m depths and from recoveries of ballasted drift bottles. Results from the first year were presented in the Final Report, Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico, 1976-1977 (U.S. Department of Commerce 1977a). General conclusions on hydrographic conditions were that water temperatures followed air temperatures, salinity reached maximum values in winter and decreased through spring in response to discharge from local streams, and vertical stratification in and around the Buccaneer Field was either weak or non-existent. Annual cycles of temperature and salinity closely paralleled conditions reported from historic observations in the area (Temple et al. 1977).

Lagrangian current measurements made in the first year with drift bottles and transponding buoys exhibited distinct differences. Transponding buoy records from eight operations conducted between July, 1976 and February, 1977 indicated a seasonal reversal in currents around the Buccaneer Field. During the summer, flow was toward the east to southeast and, in fall and winter, west to southwest which is similar to the circulation reported from drift bottle recoveries by Kimsey and Temple (1963) and from interpretations of distribution of hydrographic structure reported in the studies of the South Texas Outer Continental Shelf (U.S. Dept. Commerce 1976a). Ballasted drift bottles were released on 10 cruises between May, 1976 and March, 1977 during the first year of the Buccaneer Field studies. From May through August, the drift bottles indicated flow to the west and southwest, unlike the eastward movement of the buoys. Releases of drift bottles during 5 cruises in October through January netted no recoveries, and in the last operation (February - March, 1977), movement was down the coast toward the west and southwest.

The circulation in the waters of the continental shelf off Texas is generally considered to be wind-driven. Franceschini (1953) related ship drift records to wind-stress patterns. Ichiye (1962) developed a wind-driven model for the Gulf and found good agreement with isohaline patterns over the northern shelf of the western Gulf. Using drift bottle recoveries from releases over the Texas shelf, Kimsey and Temple (1964), Watson and Behrens (1970), and Hunter et al. (1974) were able to associate some details in current variations with local winds. The South Texas Outer Continental Shelf studies (U.S. Dept. Commerce 1976a) showed that the alongshore currents over the Texas shelf undergo distinct seasonal reversals, are part of a larger-scale pattern covering the northwestern Gulf and are associated with monthly mean patterns of Ekman transport.

Dispersion models have been employed for analyses of potential environmental impacts for various activities along the continental shelf of the Gulf of Mexico, e.g., with brine disposal for strategic petroleum storage in salt domes along the Louisiana-Texas coast (U.S. Dept. Commerce 1977b-e). However, these studies have lacked observational data and have been directed toward specialized applications. Since Pritchard and Carpenter (1960) demonstrated the use of a fluorometer in measuring dispersion in natural bodies of water, fluorescent dyes have been used extensively in examining oceanic diffusion rates. Results from 20 sets of dye experiments have been compiled by Okubo (1971) to describe relations between horizontal diffusion characteristics in the ocean. From this analysis, he developed a set of diagrams from which one can obtain the mean statistical features of marine diffusion. However, Okubo points out that there is more than an order of magnitude spread in these results, which he attributes to the state of dynamic conditions.

METHODS AND MATERIALS

Two studies were carried out during the second year: dye experiments to provide a description of diffusive characteristics of the waters around the Buccaneer Field and analyses of wind and Eulerian and Lagrangian current records to examine transport dynamics. Observations from the dye studies, daily positions of transponding buoys, hydrographic records from cruises, and hourly averages of anemometer and current meter records have been filed with the Data Manager at the Fisheries Engineering Laboratory, NMFS, Bay St. Louis, Mississippi.

Dye Studies

A series of three seasonal dye experiments were conducted with experiment design based around a set of recommendations offered by Okubo (1971). Dye operations were conducted on August 17, 1977 (summer), November 11, 1977 (fall) and February 10, 1978 (winter). The studies were conducted seasonally in anticipation of differences in: (1) stratification (stratified in summer, active overturning in fall, and vertically homogenous in winter), (2) wind regimes (steady south to southeast in summer, variable in fall and more northerly in winter) and (3) currents (typically eastward in summer, variable in fall and west to southwest in winter).

Procedures were similar in all three dye studies with some alteration for the fall and winter experiments, based on experience gained from the summer operation. Ten gallons of water soluble Rhodamine WT Liquid dye (20% aqueous solution, manufactured by E. I. duPont de Nemours & Co., Inc.) was released on the surface from shipboard each time. The dye was poured out as quickly as possible so as to represent an instantaneous point source. The vessel (R/V Gus III in summer and R/V Rachel Carson in fall and winter operations) was allowed to drift away from the dye patch and was kept away from the dye until it was felt that the plume was large enough so the boat's passage through it would not appreciably affect the spreading (about 20-30 minutes).

From aboard ship, vertical penetration and horizontal concentration of the Rhodamine dye were measured using a Turner Assoc. Model 111 Fluorometer with continuous flow arrangement and strip-chart recorder, connected to a submersible pump at the end of a 50-foot garden hose. Trying various settings and filters on the fluorometer, it was found that virtually no gradients in relative concentration occurred; i.e., readings were almost always either at background levels or off-scale (>100% on most coarse settings). It was noted during field operations that visual boundaries of the dye plume coincided with fluorometer shifts from off-scale to background levels, meaning that the limits of the dye plumes could be mapped from aerial photographs. Shipboard tracking of the dye lasted for about 4-5 hours each time.

Hydrographic sampling of temperature and salinity structure was conducted from the vessel before and during each dye experiment. Temperature was measured using Sippican Expendable Bathythermograph (XBT) system and T-10 XBT probes (0-200 m depth range). Vertical salinity structure was determined with samples drawn from Nansen bottles set at depths dependent on temperature structure. Rough determinations were made aboard ship with a hand-refractometer and final values were from titration by personnel of the Galveston Laboratory, NMFS, of samples returned to the laboratory. Wind speed and direction was measured aboard ship at various times during each dye study using a hand-held anemometer. Smoke bombs were also released during each experiment and recorded in aerial photographs against the backdrop of the dye plumes.

Features and dimensions of the dye plumes were determined by means of time-series, color aerial photographs. This service was provided under contract by Schuh Commercial Photography, Galveston, using hand-held cameras aboard fixed-wing aircraft operating out of Galveston airport. Photographs were taken every 15 minutes for about 3 hours after dye release. With each photograph, records were kept of time of day when photograph was taken, headings of plane and photograph, altitude and camera attitude off horizontal. Airplane altitudes ranged from about 60 m to 760 m and attitude of the photograph angle was typically about 60° off horizontal.

Dimensions of the dye plume were calculated from the aerial photographs by scaling from the vessel when it was in the dye plume in the photographs. (Vessel was rotated 90° for each 15 minute photographic pass so that dimentions of major and minor axes of plume could be scaled from boat length.) Length (major axis) and width (minor axis) were each found to increase linearly with time for each experiment. Tracings of the dye plumes from the photographs were scaled to the linear length and width dimensions and corrected to the true nadir views. Horizontal area covered by the dye for each 15 minutes was determined using a Bausch & Lomb Omnicon Scanning Image Analysis System available at the NMFS Narragansett, Rhode Island Laboratory.

Movements of the dye plumes were determined by radar fixes from aboard ship off Platform 288-A. In each of the three dye experiments, the dye was released about 2- to 3-km from Platform 288-A and radar fixes of distance and bearing were taken every 15 minutes. To represent the subsequent movement of the dye plume, pairs of drifting, transponding buoys drogued at 1 m and 10 m depths were deployed in the plumes and tracked for about a week. Buoys used and procedures followed in land-based tracking were the same as described in the report of the first year's effort in the Buccaneer Field studies (U.S. Dept. Commerce 1977a). During the summer dye experiment a pair of buoys were set out at the conclusion of the photographic mission and, on the following morning, four more buoys were deployed around the Buccaneer Field. From aboard ship we noticed that the pair of buoys (drogued at 1 m and 10 m) that were deployed in the dye quickly separated from one another, along the long axis of the plume. Because of this observation buoys in the dye were deployed during the middle of the photographic mission for the fall and winter experiments. By scaling the location of these buoys from the photograph series, vertical shear relative to the plume could be determined. Records and results from the dye studies are given in Table 1 and hydrographic station data are included in Table 2. Prior to each dye experiment, notification was sent to the U.S. Coast Guard, District Commander in New Orleans, Louisiana describing the nature and expected dates of the operation.

Currents and Circulation

Three sets of current records are available for the waters around the Buccaneer Field: (1) drift bottles released during the first year's work, (2) transponding buoys deployed during the first year and deployed with dye studies during the second year, and (3) current meter measurements made at Platform 288-A.

Drift bottles were released and transponding buoys were deployed and tracked by personnel of the NMFS Galveston Laboratory during the first year of the Buccaneer Field studies. Drift bottles were released on 16 cruises conducted from May, 1976 through March, 1977 and 56 transponding buoys were deployed during 11 operations of the first year beginning in July, 1976, continuing into August of 1977. As part of this year's studies, an additional 14 buoys were deployed during the three dye studies (August, 1977; November, 1977; February, 1978). After examining the buoy records, it was realized that for the 4 month period of mid-February through mid-June, buoys had been deployed only once during the two years. In that one operation (6 buoys in May, 1977) tracking of the buoys lasted a maximum of only 2 days. Concluding that this was an inadequate coverage for the spring, an additional deployment of 6 buoys was conducted in late April, 1978. In total, 77 buoys were deployed during 15 operations spread between July, 1976 and April, 1978. Description of methods and results for the drift bottle and transponding buoy operations (for the first 8 buoy deployments, through February, 1977) were reported in the Annual Report for the first year's studies (U.S. Dept. of Commerce 1977a). Procedures and equipment for the 7 later buoy operations were the same as described in that report. Records for the releases and tracking of transponding buoys from all 15 deployments are given in Table 3. Hydrographic observations collected on cruises subsequent to February, 1977 are included in Table 2. (May, 1976 - February, 1977 observations were reported in Final Report of first year's work, U.S. Dept. Commerce 1977a.) Analyses and portrayals of transponding buoy results by automatic data processing were provided under contract with the University of Rhode Island, Kingston, R.I. (Dr. H. J. Petersen, Principal Investigator).

As part of the Ocean Current Measurement Program, sponsored by Shell Development Co., Exxon Production Research Co., AMOCO Production Co., Mobil Research and Development Corp., and Chevron Oil Field Research Co., current meter and wind observations were recorded from instruments mounted at Platform 288-A of the Buccaneer Field. The program was carried out by Evans-Hamilton, Inc., Houston. Permission was graciously granted by the sponsors to acquire copies of these data. Measurements that may have been recorded during high storm conditions were to be excised by the sponsors for proprietary reasons. Although the instruments had been operating for a number of years, terminating in December, 1976, cost constraints limited the amount of data we could actually use. Data for the year 1976 was chosen because of the opportunity to inter-compare measurements from (1) current meters, (2) drift bottles, and (3) transponding buoys. Processing, analyses and portrayals of the wind and current meter measurements was conducted under contract with Evans-Hamilton, Inc., Houston. A description of the equipment, records, and processing procedures is given in Part B, provided by Robert C. Hamilton of Evans-Hamilton, Inc.

In order to examine correspondence between winds and the movements of the drifting, transponding buoys, wind records of daily prevailing direction and average speed at Galveston were acquired from the Galveston Station of National Weather Service. These were compiled to give resultant wind vectors for elapsed time between buoy tracking. Derived values are listed in Table 3.

In some of the analyses, particularly with regard to features in the dye studies, tidal currents were found to be important. Data given for tidal currents are taken from National Ocean Survey predictions of tidal currents for Galveston Bay entrance (U.S. Dept. Commerce 1976b and 1977f).

RESULTS

Dye Studies

A number of similarities and differences were found in the growth and movement of the plumes in the three dye studies. A series of figures (Figures 1-5) are presented, along with Table 4 to summarize the characteristics of the spread and movement of the dye. Figures 1 (a-c) illustrate the movement of the plumes, local wind conditions and spreading configuration of the dye during each of the three dye experiments. Also shown in Figures 1 (a-c) are the movements of drifting transponding buoys, relative to the dye patches. (Movements of buoys on subsequent days are presented in the section on Circulation). Figures 2 (a-c) display the rates of increase in principal axial, horizontal dimensions of the plumes. Speed of movement and growth along the direction of transport in relation to predicted tide currents of the area are shown in Figures 3 (a-c). Comparison of increase in areal coverage by the dye is shown in Figure 4. Area values were computed from Image Scanner analyses of tracings from aerial photographs which had been scaled to the linearized, length-width dimensions of Figures 2 (a-c). For each value of area, an equivalent radius ($\equiv \sqrt{\text{Area}/\pi}$) was calculated, equating the horizontal dye coverage to a circle of equal area. Comparison of results of these values for the three experiments is shown in Figure 5. For purposes of comparison, the curves of Figures 4 and 5 were shifted so that values equalled zero at the time the dye was released. Rates of change of the various dimensions of the three dye plumes are summarized in Table 4.

In August, dye was released about 3 km north of Platform 288-A. The dye moved northward with the wind and spread rapidly along that north-south direction (Figures 1a and 2a). As indicated by fluorometer measurements, the dye quickly (within 1 hour) penetrated to 5 m depth and did not go deeper for the 3-1/4 hours of sampling. During the survey a weak thermocline was present which extended to about 5 m depth (surface temperature 30.4°C, 5 m temperature 30.1°C) and surface salinity was about

0.2 o/oo less than at 9 m, implying that the dye remained in weakly stratified surface layer. Sampling the following morning indicated that the vertical structure in the upper 10 m had been destroyed overnight. Drifting, transponding buoys, drogued to 1- and 10-m depths were deployed in the dye plume at the conclusion of the aerial photography mission. From aboard ship we noted that the 10-m buoy quickly moved southward, relative to the northward moving plume (as depicted in Figure 1a). Land-based fixes of the buoy positions two days later showed that both buoys had moved northwestward, but the 10-m buoy was located about 1.3 km south of the 1-m buoy.

For the fall experiment (November), dye was released about 2 km west of Platform 288-A. As in summer, the plume moved northward and spread rapidly along its north-south axis, but the movement was opposite a northerly wind (Figures 1b and 2b). About an hour after release, the dye had penetrated to about 7 m depth and later sampling indicated the dye did not penetrate further. No temperature structure was detected through the depth of dye penetration, although XBT data showed a warm inversion layer on the bottom, beginning at 17 m depth. There was about a 0.5 o/oo increase in salinity through the upper 10 m of the water column. Drifting, transponding buoys, drogued to 1- and 10-m depths were deployed in the dye plume during the photographic overflight. Movements of the buoys relative to the plume were determined from scaling off the photographs and revealed that the 10-m buoy remained with the plume, whereas the 1-m buoy moved southward through the dye, left the plume and continued moving southward away from it (Figure 1b). Both buoys were moving northward, but the 1-m buoy was slower and, relative to the plume, travelled south with the wind. Experience with this type of buoy has indicated that there is little or no sail-effect from the antenna mast. Fluorometric measurements made after the buoy deployment indicated that there was no dye present at the 1-m level. Therefore, at least the upper meter of the water column was apparently being dragged by the wind and if dye had been present in that surface layer, the increase in length of the plume would have been considerably larger than indicated in Figure 2b. (Estimates of this potential additional spreading based on buoy movement are developed in the Discussion section.) Land-based tracking of the buoys on the next day showed their motion to have changed from the initial northward course to southeastward.

The third dye study was conducted in February, 1978. Dye was released about 2 km west of Platform 288-A and moved westward during northerly winds (Figure 1c). Unlike the elongated shapes observed during summer and fall, the winter patch was more circular (Figure 1c) with rates of increase in length (along direction of movement) and width (wind direction) almost equal (Figure 2c). Vertical sampling with a fluorometer indicated the dye penetrated to 9 to 12 m deep, and similar to fall conditions, only minor concentrations of dye were found at 1 m depth. Hydrographic sampling showed the water to be virtually homogenous from surface to bottom. Buoys drogued to 1- and 10-m depths were deployed in the plume and, from aerial photography interpretation, both stayed with the westward moving plume. Although the buoys moved eastward relative to the center of the plume, they maintained constant position within the spreading dye. Winds diminished during the dye study, as evidenced by the presence of whitecaps in aerial photographs at the beginning of operations and their absence after about 45 minutes. Land-based fixes on the buoys the following day showed that they had continued moving westward with little-or-no separation between them.

Comparisons between the results of the three, seasonal dye studies are shown in Figures 4 and 5 and Table 4 and are described in the Discussion section.

Currents and Circulation

Through the first two years of the Buccaneer Field studies, three different methods were employed to assess the circulation in the shelf waters of the upper Texas coast: drift bottles, drifting, transponding buoys and current meters at Platform 288-A. Comparison of results from these techniques shows considerable dissimilarity. Drift bottles were released on 16 cruises between May, 1976 and March, 1977. Of the 865 drift bottles released, 197 were recovered and reported and 94 of these recoveries were used for estimating rates of movement. Seventy-seven drifting, transponding buoys were deployed during 15 cruises between July, 1976 and April, 1978 with 66 of these buoys providing at least one day's record of movement and 49 buoys were tracked for more than 48 hours (longest record for a buoy was 15 days). Hourly averages of current meter records collected in December, 1975 through December, 1976 were examined. At the single mooring, current meters were at depths of 4-, 10-, and 17.7-m. Data from at least one of the current meters was available in each of the 13 months. Associated anemometer records provided some values in all months from December, 1975 through December, 1976.

Drift Bottles

Results from drift bottle releases were presented in the first year's report (U.S. Dept. Commerce 1977a) and indicated flow principally toward the southwest (downcoast) and onshore for May through August, 1976 and in February-March, 1977. No recoveries were reported within 30 days for 5 cruises conducted between September, 1976 and January, 1977. Four major problems inherent in the use of drift bottles for determining currents should be pointed out: (1) since drift bottle operations depend mainly on beach recoveries, offshore flow can only be ascertained from the absence of recoveries; (2) only the resultant drift between the time and location of release and recovery can be examined and, therefore, major current shifts between these times may be missed if the bottle's transit transcends such a shift; (3) speed estimates are highly dependent on how long the bottle remains unnoticed on the beach; and (4) drift bottles are drogued to the very surface layer with a relatively large sail and are quite likely to be transported as much by the winds as by the current.

Drifting Buoys

Movements of the drifting, transponding buoys are shown in the series of computer-generated map-plots of Figures 6-24. (Land-based fixes on buoy positions never indicated that the buoys were actually on land and the apparent movement across the beach in these figures is the result of insufficient resolution in the computer map of coastline.) Included in Figures 6-24 are the results of those buoy operations that were reported in the results of the first year's effort. A composite of the trajectories of all the buoys released in and around the Buccaneer Field is shown in Figure 6. From this depiction it is apparent that most of the flow was directed parallel to the coast or offshore with only limited brief excursions shoreward. Movements of buoys during each of the fifteen deployments are shown in Figures 7-21, along with diagrams depicting local winds during the days of buoy tracking. In Table 3 are listed the overall statistics for each buoy and the local wind conditions reported by Galveston Weather Station of the National Weather Service, NOAA. Winds used in these analyses are daily average speeds (average of hourly observations) and prevailing direction (most frequent octant from which winds were blowing based on hourly observations), which are the standard reporting formats for the Galveston Weather Station. Therefore, it should be noted that winds during any one day may have been from a variety of directions and, even with steady winds may have been from a direction as much as 22° to the right or left of the reported octant bearing. Since the Buccaneer Field is near the coast, currents around the field might be strongly affected by coastal deflection. With this consideration, a number of the analyses of buoy and current meter records are based on quadrants relative to the about 60°-240° tending coastline of the area, with the definitions: upcoast (15°-105°), offshore (105°-195°), downcoast (195°-285°) and onshore (285°-15°).

A chronology of the circulation patterns based on the movements of the drifting, transponding buoys is as follows:

> During July and early August, 1976 (Figures 7 and 8) 10-m drogued buoys moved toward east-southeast (offshore with an upcoast component) at about 90° to the right of mainly south to southwest winds. During September into October (Figures 9 and 10) winds became variable and buoys, drogued at various depths (Table 3) indicated that flow direction rotated clockwise from the summer orientation, ending up toward shore and downcoast. With the changing current pattern, speeds were slower. By mid-October and persisting through February, 1977 (Figures 11-14) surface and 10- to 18-m currents were directed decisively downcoast. During this period, winds were principally from the east, driving the water toward shore and downcoast.
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> The short record of buoy drift in May, 1977 indicates that the flow pattern was again undergoing change (Figure 15), with motion mainly onshore with southerly winds and diminished downcoast transport. By June, currents had reversed from the winter pattern, flowing upcoast to the right of steady southerly winds (Figure 16). In early August, buoys initially were moving east and southeast, but then when winds turned to southeast, the one buoy still transmitting (drogued at 1 m) turned around to more downcoast and onshore (Figure 17). By mid-August buoys at first

showed continued onshore flow (Figure 18) but with southwest winds, shifted toward east or upcoast as in June. In November, 1976 and February, 1978, the clockwise rotation of current trajectories appears, as in the previous year, with variable but mainly offshore flow in November and downcoast flow with east winds fully established in February of 1978. During the last buoy operation (April, 1978) the buoys first seemed to be following around an eddy-type current before settling in to distinct downcoast transport (Figure 21).

Based on these buoy movements, distinct seasonal reversals in the currents are apparent. Composite plots of buoy movements for each season are shown in Figures 22-24. Buoys tracked during summer periods generally moved offshore and all buoys except one displayed net displacements upcoast (Figure 22). The winter pattern (including fall) was downcoast with both onshore and offshore migrations (Figure 23). The more sluggish and variable pattern of buoy movements during September and late April-early May made those appear to be transitional periods (Figure 24), although net downshore transport prevailed.

The circulation cycle and current variability over the two years of buoy deployments are further shown in Figures 25 and 26. In Figure 25 are displayed the daily movements of all the buoys. From this display it is apparent that (1) there is little or no vertical gradient to the currents, (2) flow may be directed most any direction at any time, and (3) there is a grouping of buoy movements around downcoast and upcoast directions, or parallel to the coast. In order to filter out the day-to-day variability and, thereby, discern the general pattern of currents, the resultant direction of movement (from buoy release location to last land-based fix) of the buoys was determined for those buoys that were tracked for more than 48 hours. These resultant directions of movement are shown in Figure 26 along with the annual cycle as estimated from the about 2 years of studies. From about September through April currents were mainly downcoast, but reversed to flow upcoast and offshore for June through August. As evidenced by the direction of movements of buoys drogued near surface and those drogued at 10- to 18-m depths, flow was generally in the same direction throughout the water column.

The seasonal pattern of currents from the buoy records are further delineated in Table 5, along with the orientation of local winds during the periods of buoy tracking. From Table 5, daily buoy movements during the summer months (June-August) were principally directed up the coast under the influence of onshore winds. This circulation, to the right of the wind, would be an Ekman transport. During winter (October-February) winds from the eastern hemisphere transported water mainly downcoast. Transitional periods (September and late April-early May) were characterized by flow as in winter (downcoast) but winds similar to those of summer (onshore). Ekman transport or transport directly with the wind and deflected by the coastline would tend to favor setting up currents upcoast during the transitional periods. However, the prevalence of downcoast buoy movements implies that forces other than local winds were governing the circulation. In the results of the studies of the

South Texas Outer Continental Shelf (U.S. Dept. Commerce 1976a), it was shown that in the shelf waters off Galveston, surface salinity decreases in spring because of increased river discharge. It was further indicated that wind-driven effects established flow that would be upcoast over much of the Texas Continental Shelf, but in the low-salinity coastal waters of the upper Texas coast, transport was downcoast. Apparently, in the waters around the Buccaneer Field, a low-salinity wedge develops during the spring period which, with the strengthened offshore salinity gradient, establishes a downcoast-directed geostrophic current that dominates over wind-driven influences. Hydrographic sampling during 1976-1978 was considered inadequate to define the salinity cycle during buoy operations. Governing conditions during early fall were less clear.

Normal-to-shore transports accounted for almost half of the daily buoy movements (Table 5). Onshore and offshore components were about equal during the two summers, which would fit with Ekman transport and downwind flow. In winter downwind flow is seen producing the almost equal onshore and offshore transports. During transitional periods onshore movements were more frequent, probably resulting from the onshore winds. Resultant buoy movements in Table 5 indicate almost total dominance of net transport parallel to shore with offshore components present in summer and winter and near-equal, net movements shoreward and seaward in the transitional periods. Further breakdown of resultant buoy movements during the transitional months shows that all the instances of net displacements toward onshore and offshore quadrants occurred in the early fall operations.

Tabulations for comparing seasonal aspects of wind and buoy speeds are listed in Table 6. Speeds of buoy movements indicate that the principally upcoast currents of summer were faster than was the mainly downcoast flow of the winter and transitional months, with weakest currents during the early fall and spring months. This seasonal pattern prevailed whether considering daily movements, net resultant speeds or averages of daily speeds (Table 6). Local, daily wind speeds were about equal during summer and transitional buoy trackings and greater in winter. However, resultant wind speeds of Table 6 were highest in summer, implying steadier winds during that season.

Further comparisons were made of buoy movements by drogue depth. It was determined that for all buoys, sorted by daily movement, resultant displacements and by seasons, current speed and direction were essentially the same in the surface layer (1- and 3-m drogue depths) and mid-depth to near bottom layer (10- to 18-m drogue depths).

Current Meter Records*

Analyses of current meter records show an annual circulation pattern similar to that observed from the movements of transponding buoys, with the distinction of layered flow showing in current meter records during summer. Anemometer and current meter measurements recorded during December, 1975 through 1976 from a mooring at Platform 288-A in the Buccaneer Field were analyzed. Current meters at this mooring were in the surface layer (4 m depth) mid-depth (10 m) and near bottom level (17.7 m depth). Results from current meters and the anemometer are presented in Part B, prepared under contract by Evans-Hamilton, Inc., Houston. In Part B are presented a description of the mooring and equipment, data recording and processing procedures, tabular summaries of monthly means and statistical distribution of data and figure displays of wind and current records in the forms of (1) time-series displays, (2) progressive vector diagrams and (3) spectral energy diagrams. As with drifting buoy results, axial components are oriented to the coastline, taken as 60° and 240° as alongshore and 150° and 330° as normal to shore. It should be expected that the proximity of the current meter mooring to the oil field structures might create some errors as compared to open-water currents.

The time-series figures and progressive vector diagrams in Part B show a variety of time scales of fluctuations in the currents and winds. The records begin in mid-December, 1975 for winds and mid-depth currents. Initially, flow is downcoast with winds toward the southwest followed by a brief period (on about the 19th) of upcoast winds and upcoast flow. Similar cycles of alternating winds continue through the rest of the month with currents shifting to be roughly with the winds. Offshore, net flow prevails. Around the 24th of December, a front apparently moved through the area, preceded by high winds of about 15 m/sec, initially blowing toward the northwest and then quickly turning to blow toward the southeast. Accompanying these high winds, a strong downcoast current developed and, with the wind shift, reversed to upcoast. During the period of current measurements in January, 1976, at mid-depth, winds were predominately toward the northeast, with currents following the winds upcoast. Brief periods of downcoast flow appear around the 18th-20th and the 25th-26th. Winds were recorded during the 25th and 26th and showed a shift toward the southwest, leading to the period of downcoast transport. Normal-to-shore flow continued weak, but appears to be somewhat offshore directed.

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* Current meter and anemometer records used here are from the Ocean Current Measurement Program, operated by Evans-Hamilton, Inc., Houston, sponsored by an industry consortium (Shell Development Co., Exxon Production Research Co., AMOCO Production Co., Mobil Research and Development Corp., and Chevron Oil Field Research Co.) and made available for this investigation by the sponsors on an "at-cost" basis for record processing via Evans-Hamilton, Inc.

In February, the progressive vector diagrams indicate that the highly variable winds of the preceding two months have become somewhat better organized to blow more steadily toward the north to northeast. The progressive vector diagram for 10-m currents in February indicates that for about the first half of the month, transport with the wind is either by Ekman transport (to the right of the wind) or following the wind and deflected to flow up the coast (toward 60°). Later in the month, as winds become more directly onshore, a weak offshore current dominates.

Generally onshore winds continued until about the last week of March. Meanwhile, mid-depth currents shifted to a fairly steady, downcoast direction. During the last week of March, winds were mainly upcoast and onshore, but currents throughout the water column were steady downcoast. Throughout the month of April, winds were quite steady from the south which, with either transport with the wind or to the right of the wind would lead to wind-driven transport upcoast. All three current meters provided useable records for the first half of April and showed currents steady downcoast and speeding up at all depths as the month progressed. Some rotation offshore with depth is indicated.

The currents of March and April from current meters and also from the buoy movements of late April and early May in 1977 and 1978 clearly were not wind-driven. Salinity around the Buccaneer Field, from results of the first year's Buccaneer Field studies (U.S. Dept. Commerce 1977a) and from results in the South Texas OCS studies (U.S. Dept. Commerce 1976a), show that this is the time of annual minimum salinity because of the high, spring discharge from rivers of the area, including the Mississippi River. Brackish water nearshore with more saline, oceanic water offshore would tend to establish a geostrophic current that would be directed downcoast. Apparently the geostrophic, or density associated, current was of greater influence than was the wind stress.

In May, winds were recorded during the first, third and fourth weeks. During the first and fourth weeks, winds were mainly upcoast, and onshore during the third week. Current records available for the month (10 m and 17.7 m only) showed that by the end of the first week of May, the results from river discharge lost their influence on at least the lower half of the water column, and wind-driven transport prevailed with mainly upcoast flow during most of the month, including the period of winds from the southwest in the last week of the month. During the third week of May, onshore winds did not establish Ekman transport, which would have favored an upcoast current, but rather downcoast flow developed. For most of June, all three current meters were operating and showed a layered flow, with downcoast flow at 4 m depth until almost the end of the month, upcoast flow near the bottom which weakened during the latter part of the month and, at mid-depth, the currents were upcoast during the first week and shifted to mainly downcoast until near the end of the month. Apparently, downcoast flow was restricted to a shallow, surface layer early in the month and this layer thickened and deepened through the month. Winds were mainly onshore for the month.

For the last few days of June, and through July, winds were directed upcoast. During this time, 10-m and 17.7-m currents returned to upcoast and surface layer flow became weak and erratic, indicating continuation of the layered circulation, but shoaling of the interface between contrasting currents. During June through July it appears as though subsurface flow was wind-driven, but a surface layer may have still been under the influence of a shallow, geostrophic-flow layer of brackish water. Although the 4-m instrument was not operating during May, this structure may have existed then. By late July the layering is seen to have almost dissipated. Since, for the months of May through July, wind energy could not have locally penetrated through the oppositely moving surface layer, then it must be concluded that the upcoast transport in the deeper layers was part of a wind-driven current of the outer continental shelf.

August winds were mainly blowing onshore and upcoast. Currents at 4-m depth underwent alternating pulses of upcoast-offshore and downcoast-onshore until about mid-month, when they settled to downcoast flow. Current measurements were not available at mid-depth. At 17.7 m flow was weak and alternated between upcoast and downcoast, not quite paralleling variations at the 4-m level.

During September and October a confusing set of patterns developed. During most of September, winds were onshore and upcoast; by late September and through October, winds were highly variable. Currents at 4-m depth were mainly onshore during September, to the left of the winds, and became steady downcoast in October. At 10 m, flow was fairly steady downcoast throughout September and steady downcoast until the end of the record in October. Near the bottom, at 17.7 m, currents were similar to those at mid-depth, but lagged by almost a month since they were upcoast in early September, weak downcoast for most of September, and only moderately steady downcoast till record's end in October. Apparently the downcoast circulation during September and October is not related to the local winds and hydrographic observations do not indicate a distinct salinity lowering at this time of year. However, in the results of the South Texas OCS studies (U.S. Dept. Commerce 1976a), it was concluded that the large scale, monthly mean, atmospheric pressure alters during these months in such a way as to favor westward transport over the northwestern Gulf. That is, the shift in mid-depth and bottom currents at the Buccaneer Field may have been in response to a large scale, seasonal change in the circulation.

During November and December only anemometer and 4-m current measurements were available. In November winds were mainly either onshore or upcoast and variable, but surface layer flow was steady downcoast. About the middle of November a particularly interesting event developed which is apparent in the time-series figures for that month. During the early hours of the 12th, winds shifted from about 5 m/sec upcoast to about 15 m/sec onshore, remaining above 10 m/sec until about noon on the 13th, when winds decreased and rotated to blowing offshore. Within an hour after the winds picked up on the 12th, surface layer currents speeded up to a strong downcoast flow. Then, mid-morning on the 14th, flow accelerated with a downcoast component of flow of about 150 cm/sec and offshore component in excess of 100 cm/sec. The resultant vector current reached as high as 180 cm/sec (3.5 knots) and remained above 150 cm/sec for five hours. The offshore component continued above 40 cm/sec for 26 hours. The high velocity, downcoast-offshore flow occurred about 20 hours after the winds calmed and the strong offshore component persisted for about two days. Apparently, the strong onshore winds piled water against the coast developing a hydraulic head. When the winds relaxed the hydraulic head was released and added to by the shift in winds to offshore, producing the abrupt, strong current. About a full day was required to relax the head. A resonant effect is also seen in the normal-to-shore component of motion, in that subsequent to the intense offshore transport, a weaker onshore current developed and lasted for about two days (until early afternoon on the 17th). The winds observed during this event would seem to be rather typical of conditions when a strong "norther" would blow through, though it seems remarkable that such strong currents would occur as far offshore as the Buccaneer Field. Unfortunately, data were not available from the 10 m and 17.7 m current meters during that time.

Currents at the 4 m current meter in December alternated between periods of upcoast and downcoast flow, with net upcoast flow resulting. The flow pattern generally paralleled the winds, which typically were toward the northeast, or upcoast.

DISCUSSION

Dye Studies

Analyses of results from the three, seasonal dye studies indicate that the ambient conditions that governed the movement and dispersion of the dye were (1) local winds, (2) tidal currents, (3) background currents, and (4) stratification of the water column. Molecular diffusion also must play a role, but cannot be evaluated from these field experiments.

Winds observed during the dye experiments were of similar speeds, but of different directions: from the south during the summer experiment and from the north in fall and winter. Orientation of winds relative to the movement of the dye plumes was with the movement in summer, opposite for fall and perpendicular during the winter operation. Tidal currents, based on National Ocean Survey, NOAA, predictions for Galveston Bay Entrance were ebbing at the beginning for all three studies, continued ebbing throughout the winter operation and reversed to flooding current about halfway through the summer and fall experiments. As depicted in Figures 3a and 3b, tidal currents had the effects of increasing and decreasing the dye plume speeds as the tide oriented with or opposite the direction of plume movement. From the speeds of movement of the dye plumes for summer and fall, given in Table 4, tidal current component can be calculated at about 0.2 km/hr, assuming ebb and flood currents of equal speed. Movement of the plumes, after subtracting out the tidal current component, was about 0.4 to 0.5 km/hr in all three cases and background currents, as determined from drift of buoys drogued to 10 m depth was apparently always in the same direction as plume movement. Comparison of drift rates between the 10-m buoys, 1-m buoys and dye plumes indicated the presence of vertical gradients in the horizontal currents which resulted from local wind-driven transport in the surface layer. This pattern was evident in the summer and fall experiments (Figures 1a and 1b) but, during the winter study, when winds were diminishing, neither buoy seemed to track with the wind (Figure 1c). Evidently, with at least these low wind speeds, a wind-driven surface layer, with its associated strong turbulence, quickly vanishes as winds diminish.

The effects of stratification on dispersion are not at all certain from these three studies, but there were indications of two aspects. As a direct effect, the rather weak temperature and salinity layering observed during the summer experiment apparently limited the dye penetration to 5 m, whereas the unstructured condition encountered in winter allowed the dye to penetrate to about twice as deep. In fall, dye penetrated to about 7 m depth in the presence of only a vertical salinity gradient. An indirect effect of stratification was that, in summer, the dye was kept nearer the surface under greater influence of wind-mixing than was the case encountered in either the fall or winter experiments.

The particular combinations in the orientation of forces relative to one another during the three dye studies allowed an opportune circumstance for observing the contribution of these forces to dispersion. Typically, the plumes elongated along the axes of wind and sub-surface, or background currents. The summer and fall plumes developed a narrow, pointed end directed upwind with a broadened head at the downwind end (Figures 1a and 1b). In the fall experiment, when wind and current were opposite each other, features were well defined: bulk of the dye was in the broad head which apparently was being dragged by the wind against the current with dye dispersed laterally by wind-induced turbulence; the narrow tail was streaming with the current with very slow transverse mixing as would be expected in the more streamlined transport along a current trajectory. With wind and current acting in the same direction in summer, and since the dye was more restricted to the wind-mixed layer, the horizontal distribution of the dye graded more smoothly from the pointed end to the broadened head. In the winter experiment, with wind and current perpendicular, the dye spread at almost equal rates along each, the wind and current directions. It could be considered that with the winter dye plume the elongation along the axis of the current was more the result of lateral turbulence with the wind, as occurred in the fall and summer plumes. However, comparing the values for rates of increase in width for summer and fall in Table 4 (35 m/hr in summer and 45 m/hr in fall) with the rate of increase in length (with the current) in winter (70 m/hr), it seems that dispersion by the current along its direction must have been about equal to the diffusive effect of lateral wind mixing.

Even with the mix of forces and differing configurations of the dye plumes, the area covered by the dye increased at steady rates (Figure 4). Equating the horizontal coverage of the plume to a circle of the same area, it was found that the radius (equivalent radius) of these areas increased linearly with time, except for a shift during slack tide (Figure 5). Since increases in length and width in each dye study proceeded at linear rates with time throughout the monitoring periods (Figures 2a-c), the shift in area and equivalent radii rates during stages of the tidal cycle gives evidence of the effect on dispersion by the tidal current. Elongation along the principal axes (length and width) was apparently unaffected by the tidal current, but during ebbing and flooding tidal currents, the area was increasing more rapidly than during slack period. This implies that the wind and current act to stretch the plume and the mixing from the tidal flow tries to fill out the area, or make the shape more elliptical. Unlike the sinusoidal curve of tide height and tidal current speed, the effect of the tidal current on transport of the plumes (Figures 3a-c) and spread, or equivalent radius (Figure 5), seems to be more of a step function. Whether the 5 m/hr decrease in rates of change of equivalent radius for the summer and fall experiments between ebb and flood tides (Table 4) is real, is uncertain. Effects of tidal flow seem to be borne out by the results from the winter dye study, when ebbing tidal current persisted through the study and no shifts were apparent in movement of the plume (Figure 3c) nor in rate of change of equivalent radius (Figure 5).

In none of the dye studies was there distinct evidence of Ekman spiraling or of striations characteristic of Langmuir circulation, as have been reported in some other dye experiments (e.g., Ichiye et al. 1964; Assaf et al. 1971). Lack of these features could be the result of (1) water depth too shallow, (2) the dye not penetrating deep enough, (3) the dye being observed for too brief a time, or (4) winds too light to develop such patterns. The greater spread in the broad head on the western side (right of the wind) of the fall dye plume (Figure 1b) may have represented a tendency toward development of an Ekman spiral. Based on the results of Gordon and Gerald (1973) the absence of Langmuir cells was probably because of the low wind speeds encountered.

An interesting facet regarding the dye plumes is the large differences that occurred in plume growth rates between the three experiments (listed in Table 4). During the three experiments, winds and currents were of similar speeds, yet the rates of growth were widely separate and the relative factor of ratios of length to width varied considerably. Differences between the winter and the two earlier studies can perhaps be explained from the facts that in winter, wind and current were perpendicular to each other (thereby each acting to stretch the plume in different directions) and that winds were dying (as evidenced by the disappearance of whitecaps which had been present when the dye was released). Movements of buoys during the winter experiment, as described in the Results section, further indicate that wind-driven effects were less then. During the summer and fall operations considerable differences developed in growth rates of length and equivalent radius, with length growth being the dominant variant (245 m/hr in summer versus 95 m/hr in fall, from Table 4).

The approximately 2.5 times greater rate of length growth during summer as compared to fall seems to have resulted from the vertical distribution of dye within a wind-driven layer of shear in horizontal motion. Evidence for this explanation comes from the results of (1) vertical fluorometric profiles of dye concentration and (2) observed movements of drifting buoys deployed in the dye plumes. As described previously when buoys were deployed with the fall experiment, dye extended to about 7 m depth, but was not present at the 1-m level. In summer, dye was at off-scale concentrations from 1 m (shallowest sampling level) to 5 m depth, and may have extended to the surface. In the summer experiment a buoy drogued to 1 m depth was observed from shipboard to remain with the northward moving plume, whereas another buoy with drogue set 10 m deep was seen to progress southward (upwind), relative to the plume. In fall, the 10-m buoy remained with the northward moving plume and the 1-m buoy moved southward (downwind) across, out and away from the dye patch. These buoy movements indicate that the winds generated shear in the horizontal flow. With wind and current in the same direction (summer) velocity decreased with depth with the wind-stress accelerating the surface layer. In fall wind and current were opposite, with the result that horizontal motion increased with depth. In the winter experiment the two buoys drogued to 1- and 10-m showed little separation indicating only minor vertical shear. Also the buoys of winter showed little or no displacement downwind. During the summer the dye remained principally within the surface, sheared layer and, it is considered, was lengthened rapidly under the influence of strong shear with associated high turbulence. In fall the plume was deeper and under less influence from wind-induced shear. Speed of movement of the buoys in the fall plume was determined by scaling off the time-lapse series of aerial photographs (Figure 1b). Since the buoys were moving in opposite directions relative to the center of the dye, difference in velocity between the 1- and 10-m levels was 150 m/hr (1-m buoy travelling at 105 m/hr southward and 10-m buoy at 45 m/hr northward, relative to the plume center).

An estimate of the effect of the near-surface shear in fall on rates of spread of material in the water can be derived. After the 1-m buoy departed from the dye, it was observed from the aerial photographs to separate from the nearest edge of the plume (southern or downwind edge) at a rate of 80 m/hr. If dye had been present that shallow, it could be expected that the plume, which was lengthening at 95 m/hr would have lengthened at a total of 175 m/hr. This would also have increased the rate of areal growth and equivalent radius. Since this proposed augmentation would have occurred downwind and beyond the broadened head of the plume, additions to areal growth rate would have been in a rectangular shape, at length growth rate of 80 m/hr and at the actual width rate of growth of 45 m/hr. From this, the resulting total rate of growth in equivalent radius for the fall plume would have been about 45 m/hr during ebb tide, 30 m/hr during slack tide and 40 m/hr during flood tide. These growth rates are still not as large as those observed for the summer plume (Table 4), but if we allowed for dye extending shallower than the 1 m depth of the buoy, it is not difficult to extrapolate rates that would be comparable to the summer conditions.

Rates of increase in width listed in Table 4 for the three dye studies provide another interesting comparison. Even with the difference in layering of the plumes in relation to the velocity shear, the width rates of growth for summer and fall are nearly the same. Examining the features of the fall dye plume (Figure 1b), it appears that the pointed tail represents that portion of the dye streaming with a current trajectory and the broad head is that region under the influence of the local wind. (Unfortunately, from shipboard this configuration was not realized and, therefore, vertical fluorometric profiling was not done in the "head" versus the "tail" to determine possible depth differences.) Based on this interpretation, it seems as though there is only minor transverse dispersion with the current and lateral growth results mainly from wind-induced turbulence, and this rate is fairly independent of depth, to at least a few meters, under conditions of similar wind speeds. With the winter operation, the plume was growing at a rate of 70 m/hr in the normal-to-wind direction (length, Table 4). This magnitude could accommodate both (1) stretching by the current, directed along the length axis and (2) the 35 m/hr to 45 m/hr growth rate resulting from lateral, wind-induced turbulence seen in the summer and fall experiments. Since in winter there was no indication of appreciable vertical shear in horizontal velocity, there is the potential implication that the rate of lateral mixing by wind is not associated with the wind's effect on vertical shear of velocity nor with the turbulence that could be expected from such shear.

Currents and Circulation

Current meter records and movements of drifting, transponding buoys both show a predominance of alongshore flow. Also, both sets of data indicate that the flow can be in any direction on any given day, but there is the implication of general, seasonal reversals in the currents, with winds and salinity distribution acting as the primary driving forces. However, the buoys indicated uniformity of flow throughout the water column, whereas the current meters show a layered flow during summer.

Drifting Buoys

Buoy movements indicated a rather distinct reversal in currents from upcoast for June through August to downcoast in October through early May. September clearly seems to be a transitional period and there is the implication that late spring may be another transitional period. Buoys drogued to 1- and 3-m depths and those drogued to 10- to 18-m depths all tend to move together, indicating homogeneity of flow throughout the water column.

In order to examine and portray the relation between local winds and buoy movements, a set of figures is presented (Figures 27-34). Figures 27-30 depict daily movements of buoys against the daily winds and Figures 31-34 portray resultant buoy movements and winds. These figures are part of the analyses prepared under contract by the University of Rhode Island, Dr. Harold J. Petersen, Principal Investigator.

Daily movements of buoys in relation to the prevailing winds for each day of tracking are shown for all the buoys in Figure 27. Although there is a good deal of scatter in the buoy movements, they tend to cluster around the alongshore directions of 240° (downcoast) and 60° (upcoast). In relation to wind direction, with winds from the north to 60° (blowing downcoast) buoy movements are generally to the right of the wind, as Ekman transport. Between 60° and 180°, buoy movements tend to be progressively more to the left of the wind. In this general direction winds have an onshore component and transport directly with the wind would tend to be deflected by the coast toward a downcoast direction, or toward 240°. Also, as the onshore component of the wind becomes more prevalent, piling up of water toward the coast could lead to an offshore, compensating transport. In this context, with winds from 60° to 150°, transport should range from directly with the wind to downcoast to an angle offshore roughly equivalent to the onshore component of the wind. Ekman transport with winds from 60° to 150° would set up currents to the right of the wind, or generally upcoast. Ekman transport does not seem to explain the buoy movements, but transport with the wind, deflected by the coastline and with instances of compensating flow offshore, does account for the observed distribution of buoy movements. Since the daily prevailing winds are reported by the Galveston Weather Station by octants, the numerous cases with winds from 180° in Figure 27 would include winds due onshore and those with an upcoast component. Winds from this octant could lead to flow with the winds (onshore), offshore because of compensatory flow, upcoast as downwind transport is deflected by the coast and offshore-upcoast by Ekman transport. Further, with transport downwind on almost due onshore winds, coastline deflection could deflect transport to either upcoast or downcoast directions. When winds were from directions greater than 180°, buoy movements tended to range from with the wind to 90° to the right of the wind, such transports resulting from coastline deflection, Ekman transport, or compensating offshore flow with onshore transport. Also in this sector of wind directions, a sizeable group of buoy movements were downcoast and onshore. These movements cannot be accounted for by wind-driven transport.

Seasonal groupings of the buoy movements are shown in Figures 28-30. Upcoast and offshore transport with winds from the south to southwest dominate during summer (Figure 28), downcoast flow was typical for winter as winds were mainly from the eastern hemisphere (Figure 29) and variable conditions occur in the transitional periods (Figure 30). During transitional periods most of the cases of downcoast and onshore movements with upcoast winds occurred. This represents a similar situation to that described in the Results section with current meter records during spring and fall. These values certainly imply that local winds do not account for the flow pattern and that, in spring, geostrophic flow from river discharge prevails and, perhaps, in fall, we are seeing the result of current changes over the northwestern Gulf by large-scale atmospheric systems.

In Figures 31-34 are shown the net, or resultant movement of the buoys in relation to resultant winds, derived from daily prevailing winds, for the period of drift of each buoy. Movements of the buoys in correspondence to wind direction follows the same logic as for the daily movements above. However, in Figures 32-34, the seasonal patterns are more distinct than in the daily movements of Figures 28-30, and the non-wind related water transport during the transitional periods again appears.

In relation to local wind direction, there seems to be no distinction between flow in the surface layer (buoys drogued to 1- and 3-m depths) and at deeper levels (drogue depths of 10- to 18-m). Lagrangian currents appear to respond to local winds in the same way throughout the water column, both with daily buoy movements and daily prevailing winds (Figures 27-30) and with resultants (Figures 31-34).

Current Meter Records

As was described in the Results section, current meter records show a general pattern of seasonal current reversals, as with the buoy data, and in contrast to the buoys, a layered structure during the summer. It was also mentioned, as is apparent in the time-series figures of Part B, that there were numerous time scales of fluctuations in the currents. By examining the frequencies of these fluctuations, we can better define the driving forces.

The kinetic energy spectral diagrams of Part B can be used to define those frequencies that contribute to the dynamics of the water, within the limits of each record length. Spectral energy diagrams are presented in two formats, the first showing how individual frequencies contribute to the total energy and the second (frequency X power density) indicating how much each frequency band contributed to the total variance. For these analyses, only continuous records can be used and with varying record lengths, magnitudes of frequency contributions cannot be inter-compared between the segments. Also, some frequencies that appear in some of the segments are not present in others. However, dominant peaks in the longer records and repetition of peaks in shorter series can define those frequency bands that provide most of the energy for circulation.

Spectral energy diagrams of Part B were examined and the main periods were determined for each current meter and the anemometer record. These values are listed in Table 7. Also shown in Table 7 are those peaks that were considered to be most dominant and, as noted in the table, were found to change seasonally. In the wind records, the one day period of variability is probably sea breeze and other periods are fitting for the passage of surface, atmospheric pressure systems. The 14-21 day band is probably on the scale of major atmospheric alterations, as in the upper atmosphere. The seasonal shift in dominant periods with wind variability could be: 3-4 days in winter for the passage of continental air masses, and the 7-8 day band of summer for maritime air masses.

Currents in Table 7 exhibit the semi-diurnal tidal period of about 1/2 day, one day variability with diurnal tides, sea breeze and/or the local inertial frequency . Other frequency bands fairly well parallel those of the winds. Seasonally different dominant periods seem to fit with those of the winds, except at mid-depth (10 m) during the summer. It is suspected that these dominant periods of 5 and 10.5 days relate to the layered current pattern of summer when, at times, the surface geostrophic current extended to mid-depth and at other times, water at this level was part of the oppositely moving, bottom current. No observations were available during winter at the 17.7 m level.

CONCLUSIONS

Dye Studies

Results from three, seasonal dye studies indicate that the spread and movement of dissolved, and perhaps, suspended particulate matter is defined by a set of characteristic conditions which are governed primarily by the local winds, tidal current, and background currents of the area and on their relative orientation to one another. At least under light wind conditions as occurred in all three experiments, areal growth and spread (defined by equivalent radius) increases linearly with time, with growth rate perhaps slightly more rapid during ebbing tidal current than during flood tide flow, and an almost step-change decrease in rates during slack tide current. Axial dimensions (length and width) also increased linearly with time, without any alteration during different periods of the tidal cycle. Non-tidal, background or ambient currents acted to stretch the dye plumes along the direction of flow with little or no lateral dispersion. Winds introduced considerable turbulent mixing, spreading the dye laterally to wind direction as well as along the direction of the wind. Spread and dispersion rates along the wind direction were considered to be strongly dependent on (1) vertical shear in horizontal velocity resulting from wind-stress and (2) vertical position of the dye within the wind-induced, shear layer. The greater the velocity shear in the layer of the dye, the greater was the rate of dispersion and spread in the downwind direction. Lateral dispersion by the wind (directed normal to the wind) seemed to be independent of vertical velocity shear. The deeper a layer of dissolved or suspended material may be, the less the rate of downwind spreading by the winds, but lateral spreading seemingly proceeds at rather constant rates at all depths to as great as at least 10 m (maximum depth of penetration for the three dye plumes).

Movements of the dye plumes were dominated by the background current, with tidal currents coupled in a rather step-wise fashion rather than by addition from the sinusoidal curve of tidal currents. Effects on transport of the dye patches by stress from the light, local winds observed seemed to be through alterations of the vertical profile of velocity by introducing shear in the upper water column.

Currents and Circulation

Analyses of movements of drifting, transponding buoys and current meter records, along with winds from anemometer and Galveston Weather Station records indicate that currents are principally directed alongshore and that these currents reverse seasonally from upcoast (toward 60°) during summer (May - August) to downcoast (toward 240°) for October through March. September and April are considered transitional periods for although the flow is basically downcoast, it is quite variable. For brief periods currents can be directed almost any direction at any time of the year.

Current meter records show a layered current pattern during summer, with the surface layer moving downcoast, and bottom flow directed upcoast. Conversely, buoy movements did not indicate such a layered circulation. Both data sets indicated that currents were directed in the same direction throughout the water column for the remainder of the year.

Stress from local winds appears to be the main driving force for the circulation, with currents mainly directed with the wind, allowing for deflection of streamlines and trajectories by the coastline and with some cases of Ekman transport to the right of the wind. Sharp departures from local, wind-driven transport develop during the transitional periods and in the surface layer during summer. During spring salinity lowering nearshore because of increased river discharge seems to establish a geostrophic current, directed downcoast, which is opposite upcoast directed wind influences. Continuation of such a geostrophic flow, but restricted to upper water column layers, would account for the layered currents noted through summer. During the one year of current meter records, this surface layer flow in the Buccaneer Field generally shoaled and thinned as summer progressed, but periods of reinforcement and deepening interceded.

Spectral energy analyses of anemometer and current meter records exhibited a variety of frequencies contributing to the variability of the currents. Notable frequencies are with astronomical tides and 3-4 day cycle of winter, continental air mass passage and 8 1/2 day development of maritime air masses during summer. Longer periods, in excess of two weeks, also appear in both winds and currents.

A particularly noteworthy event was recorded with the current meters and anemometer in November of 1976. A fairly strong cold front apparently approached and moved through the area. Strong onshore winds piled water against the coast and, following frontal passage with winds shifted to blow offshore, a strong, temporary, offshore and downcoast current of about 180 cm/sec developed.

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LITERATURE CITED

Assaf, G., R. Gerard and A. L. Gordon.
1971. Some mechanisms of oceanic mixing revealed in aerial photographs. J. Geophys. Res., 76: 6550-6572.

Franceschini, G.A.
1953. The distribution of the mean monthly wind stress over the Gulf of Mexico. Texas A. & M. Res. Found., Sci. Rep. No. 1: 1-18.

Gordon, A. L. and R. D. Gerald
1973. Wind drift currents and spread of contaminants in shelf water. Final report to U.S. Coast Guard, U.S. Dept. Transportation by Lamont-Doherty Geol. Obs. of Columbia Univ: 1-64.

Hunter, R. E., G. W. Hill and L. E. Garrison.
1974. Maps showing drift patterns along the south Texas coast, 1970-1973. U. S. Geol. Survey, Misc. Field Studies, Map MF-623: 2 sheets.

Ichiye, T.
1962. Circulation and water mass distribution in the Gulf of Mexico. Geofisica Internacional (Mexico), 2 (3): 47-76.

Ichiye, T., H. Iida and N. B. Plutchak.
1964. Analysis of diffusion of dye patches in the ocean. Tech. Rep. No. CU-8-64, Lamont Geol. Obs. of Columbia Univ. (unpublished manuscript): 1-16.

Kimsey, J. B. and R. F. Temple.
1964. Currents on the continental shelf of the northwestern Gulf of Mexico: U.S. Bur. Comm. Fish. Circ. 161: 23-27.

Okubo, A.
1971. Oceanic diffusion diagrams. Deep-Sea Res. 18: 789-802.

Pritchard, D. W. and J. H. Carpenter.
1960. Measurements of turbulent diffusion in estuarine and inshore waters. Bull. Int. Ass. Sci. Hydrol., No. 20: 37-50.

Rath, R. J. and B. H. Francis.
1977. Modeling methods for predicting oil spill movement. Rep. to Oceanographic Comm. of Washington by Oceanographic Inst. of Washington, Seattle. 99 p.

Temple, R. F., D. L. Harrington and J. A. Martin.
1977. Monthly temperature and salinity measurements of continental shelf waters of the northwestern Gulf of Mexico, 1963-1965. NOAA Tech. Rep. NMFS, SSRF-707, 26 p.

U. S. Dept. Commerce
1976a. Environmental studies of the South Texas outer continental shelf, 1975. U. S. Dept. Commerce, NOAA Final Rep. to Bur. Land Management, Vol. II, 290 p., 174 fig.

LITERATURE CITED (Continued)

U.S. Dept. Commerce
1976b. Tidal Current Tables 1977, Atlantic Coast of North America. U.S. Dept. Commerce, NOAA, NOS, 215 p.

U.S. Dept. Commerce
1977a. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1976-1977. W. B. Jackson (ed.) NOAA Annual Rep. to Environmental Protection Agency. NMFS/SEFC, Galveston Lab., Galveston, TX, 759 p.

1977b. Analysis of brine disposal in the Gulf of Mexico, Bryan Mound. U.S. Dept. Commerce, NOAA, EDS Rep. to Fed. Energy Admin., 129 p.

1977c. Analysis of brine disposal in the Gulf of Mexico, West Hackberry. U.S. Dept. Commerce, NOAA EDS Rep. to Fed. Energy Admin., 84 p.

1977d. Analysis of brine disposal in the Gulf of Mexico, Capline Sector. U.S. Dept. Commerce, NOAA, EDS Rep. to Fed. Energy Admin., 107 p.

1977e. Analysis of brine disposal in the Gulf of Mexico, Bill Hill. U.S. Dept. Commerce, NOAA, EDS Rep. to Fed. Energy Admin., 105 p.

1977f. Tidal Current Tables 1978, Atlantic Coast of North America. U.S. Dept. Commerce, NOAA, NOS, 214 p.

Watson, R. L. and E. W. Behrens.
1970. Nearshore surface currents, southeastern Texas Gulf Coast. Contr. Mar. Sci., 15:133-143.

APPENDIX

Table 1. Observations from dye studies.

Dye Patch Position				Dye Patch Dimensions					
				Major Axis		Minor Axis			
Time (Local)	Elapsed Time	Distance from Platform 288-A (km)	Bearing from Platform 288-A	Length (m)	Axis Orientation	Width (m)	Axis Orientation	Area ($10^3 m^2$)	Depth Penetration (m)
Summer Dye Study - August 17, 1977 Winds: 2-5 m/sec from South Bottom Depth: 18m									
1400	0:00	3.0	354°	27	N-S	37	E-W	0.59	--
1415	0:15	3.1	354	--		47		2.09	--
1430	0:30	3.1	003	130		--		4.44	--
1445	0:45	3.1	003	--		--		6.02	--
1500	1:00	3.2	360	255		85		12.68	5
1515	1:15	3.2	005	345		--		20.16	--
1530	1:30	3.3	360	--		--		34.74	--
1545	1:45	3.3	004	--		--		41.28	--
1600	2:00	3.4	004	540		95		45.70	4
1615	2:15	---	---	555		--		51.42	--
1630	2:30	3.7	355	--		--		63.77	--
1645	2:45	3.9	003	--		130		75.70	--
1700	3:00	3.9	355	740		--		88.27	--
1715	3:15	4.1	003	845		150		106.65	3
Fall Dye Study - November 11, 1977 Winds: 2-4 m/sec from North Bottom Depth: 21m									
1040	0:00	2.1	240°	69	N-S	27	E-W	1.02	--
1110	0:30	1.8	245	125		--		2.56	--
1125	0:45	1.8	255	135		67		3.88	--
1140	1:00	1.8	260	168		--		5.41	--
1155	1:15	1.8	255	168		--		7.23	7
1210	1:30	1.8	255	--		93		9.08	--
1218	1:38	---	---	--		88		----	--
1225	1:45	1.8	260	250		105		11.6[illegible]	--
1240	2:00	1.6	275	--		125		13.27	--
1255	2:15	1.8	280	265		--		13.96	--
1310	2:30	1.8	275	300		135		14.77	7
1325	2:45	1.8	290	325		--		15.73	--
1337	2:57	1.8	285	365		170		17.28	--
1358	3:18	2.1	295	--		190		20.02	--
1410	3:30	2.1	300	425		195		23.43	--
Winter Dye Study - February 10, 1978 Winds: 3-4 m/sec from North Bottom Depth: 21m									
1055	0:00	2.1	260°	21	E-W	24	N-S	0.17	--
1110	0:15	2.1		--		--		0.72	--
1125	0:30	2.3		54		49		1.82	--
1140	0:45	2.3		67		65		3.52	--
1210	1:15	2.6		109		98		7.18	--
1240	1:45	2.8		135		125		12.92	--
1255	2:00	2.8		165		140		15.80	>5
1310	2:15	3.1		170		--		18.84	--
1325	2:30	3.1		190		175		24.16	12
1340	2:45	3.3		220		1[illegible]		26.82	--
1445	3:50	---		--		--		----	9
1515	4:20	3.9		--		--		----	--

Table 2. Temperature and salinity observations collected during cruises of May, 1977 - April, 1978.

Date	Time (GMT)	Station Position		Bottom Depth (M)	Observation Depth (M)	Temperature (°C)	Salinity (0/00)
		Latitude (N)	Longitude (W)				
May 5, 1977	1615	29°00.0'	94°49.5'	18	0	23.5	30.5
"	1730	28°52.0'	94°41.5'	19	0	23.0	32.5
"	1840	28°44.7'	94°34.6'	24	0	22.7	36.0
June 18, 1977	0425	29°00.0'	94°49.5'	18	0	27.5	30.5
"	0645	28°52.0'	94°41.5'	19	0	----	33.0
"	0915	28°44.7'	94°34.6'	24	0	----	33.0
July 14, 1977	0220	28°52.1'	94°41.8'	20	0	24.8	33.5
"	"	"	"	"	20	23.0	33.5
"	0530	28°51.1'	94°42.4'	20	0	24.5	33.0
"	"	"	"	"	20	23.0	34.0
"	1820	28°49.0'	94°46.1'	21	0	25.5	34.9
"	"	"	"	"	21	24.5	36.0
"	1930	28°52.6'	94°41.9'	20	0	26.0	35.5
"	"	"	"	"	20	23.5	35.5
"	2210	28°53.5'	94°41.4'	20	0	25.5	35.0
"	"	"	"	"	20	23.4	35.0
July 15, 1977	0100	28°55.3'	94°37.6'	21	0	25.0	33.0
"	"	"	"	"	21	24.5	33.0
August 1, 1977	1900	28°52.0'	94°41.5'	20	0	30.3	34.3
"	"	"	"	"	20	29.3	34.0
"	2100	28°44.7'	94°34.6'	24	0	29.8	34.5
"	"	"	"	"	24	28.1	36.0
August 17, 1977	1755	28°55.5'	94°41.2'	18	0	30.1	34.3
"	"	"	"	"	9	30.0	34.5
"	"	"	"	"	18	29.9	34.5
"	2220	28°55.5'	94°41.2'	18	0	30.4	35.0
"	"	"	"	"	18	30.0	34.5
August 18, 1977	1410	28°53.8'	94°44.3'	17	0	30.0	34.9
"	1500	28°53.2'	94°38.7'	22	0	30.0	34.1
"	"	"	"	"	15	30.0	34.0
"	"	"	"	"	21	29.5	34.0
November 11, 1977	1630	28°53.5'	94°42.6'	21	0	23.0	34.0
"	"	"	"	"	16	23.0	----
"	"	"	"	"	21	24.1	34.5
"	2030	28°54.5'	94°42.6'	20	0	23.2	34.0
"	"	"	"	"	10	23.0	34.5
"	"	"	"	"	16	23.0	----
"	"	"	"	"	20	24.0	34.3

Table 2. (Continued)

Date	Time (GMT)	Station Position		Bottom Depth (M)	Observation Depth (M)	Temperature (°C)	Salinity (0/00)
		Latitude (N)	Longitude (W)				
February 10, 1978	2015	28°53.5'	94°43.8'	21	0	12.5	35.0
"	"	'	"	"	5	12.6	34.9
"	"	'	"	"	21	12.6	34.9
April 25, 1978	1625	28°53.2'	94°41.0'	22	0	20.9	34.0
"	"	"	"	"	10	20.2	----
"	"	"	"	"	22	20.1	34.1
"	1745	28°44.7'	94°34.6'	25	0	20.6	34.0
"	"	"	"	"	5	20.0	----
"	"	"	"	"	16	20.0	----
"	"	"	"	"	25	19.8	35.1
"	2000	29°00.0'	94°49.5'	20	0	21.1	32.8
"	"	"	"	"	10	20.2	----
"	"	"	"	"	20	20.4	----

Table 3. Summary of records of releases and movements of drifting, transponding buoys and associated winds, July, 1976 - April, 1978. (Winds derived from records of Galveston Weather Station.)

								Resultants			
Release Data					Buoy Movement			Net Buoy Movement		Winds	
Date	Latitude (N)	Longitude (W)	Buoy Number	Drogue Depth (m)	Days Tracked	Total Distance Travelled (km)	Average Speed (cm/sec)	Direction (°t)	Speed (cm/sec)	From (°t)	Speed (m/sec)
Jul 13, 1976	28°55.9'	94°45.5'	197	10	1	9.3	43.1	264	43.1	180	4.6
"	28°52.0'	94°41.5'	198	10	3	63.9	23.2	107	15.2	150	5.5
"	28°48.7'	94°38.5'	199	10	3	72.3	26.3	114	9.8	180	5.5
"	28°53.5'	94°36.0'	200	10	6	105.6	20.2	117	15.8	187	5.0
"	28°57.2'	94°39.7'	201	10	7	107.5	17.3	117	15.7	186	4.9
Jul 27, 1976	28°54.3'	94°44.2'	204	10	10	172.3	20.4	101	11.2	217	2.8
"	28°51.5'	94°47.7'	205	10	6	86.2	17.2	101	16.9	224	4.8
"	28°43.7'	94°43.1'	206	10	1	13.9	19.8	117	19.8	180	5.3
Aug 31, 1976	28°52.0'	94°41.5'	210	1	3	32.4	13.4	306	9.1	186	4.6
"	28°52.0'	94°41.5'	208	14	6	53.7	10.7	179	3.1	211	2.9
"	29°00.0'	94!49.5'	207	10	9	66.7	8.7	238	2.3	197	2.4
"	28°44.7'	94°34.6'	211	1	2	30.6	20.7	300	16.7	180	5.1
"	28°44.7'	94°34.6'	212	18	6	78.8	16.0	157	10.2	212	2.9
Sep 23, 1976	28°52.0'	94°41.5'	237	1	15	95.4	7.4	257	3.4	303	0.6
"	28°52.0'	94°41.5'	209	14	1	17.6	23.8	270	23.8	227	2.5
"	29°00.0'	94°49.5'	228	10	7	43.5	7.3	286	5.0	255	1.2
"	28°44.7'	94°34.6'	236	1	6	53.7	10.7	285	13.1	230	1.7
"	28°44.7'	94°34.6'	230	18	1	38.9	58.4	290	58.4	233	2.6
"	28°44.7'	94°34.61	232	18	11	189.0	20.3	237	5.9	210	1.4
Oct 18, 1976	28°52.0'	94°41.5'	240	1	9	88.0	11.5	256	9.7	092	2.2
"	28°52.0'	94°41.5'	223	14	3	38.9	15.5	262	13.4	018	3.7
"	29°00.0'	94°49.5'	226	10	4	53.7	15.5	262	13.6	051	2.4
"	28°44.7'	94°34.6'	225	1	9	126.9	16.7	257	11.9	090	2.1
"	28°44.7'	94°34.6'	239	3	9	88.9	11.7	245	8.2	090	2.1
"	28°44.7'	94°34.6'	227	18	1	31.5	46.1	287	46.1	047	2.5
Nov 11, 1976	29°00.0'	94°49.5'	251	1	0	No Signals Received					
"	29°00.0'	94°49.5'	229	10	1	22.2	22.8	237	22.9	045	10.3
Jan 18, 1977	29°00.0'	94°49.5'	233	1	13	242.7	22.0	197	13.9	072	1.8
"	29°00.0'	94°49.5'	231	10	10	187.2	22.1	222	9.5	061	1.1
"	28°52.0'	94°41.5'	238	1	6	64.8	12.6	212	2.7	071	2.2
"	28°52.0'	94°41.5'	216	10	1	13.9	16.8	072	16.8	000	2.5
"	28°44.7'	94°34.6'	234	1	10	108.4	12.4	250	2.7	049	1.3
"	28°44.7'	94°34.6'	217	10	3	38.0	14.2	103	13.7	013	1.5
Feb 9, 1977	28°52.0'	94°41.5'	219	1	7	100.1	17.8	233	13.7	055	1.7
"	28°52.0'	94°41.5'	220	10	0	No Signals Received					
"	28°52.0'	94°41.5'	222	10	1	14.8	21.6	277	21.7	090	6.4
"	28°44.7'	94°34.6'	214	10	2	26.9	19.7	265	18.3	109	6.2

Table 3. (Continued)

Release Data					Buoy Movement			Resultants			
								Net Buoy Movement		Winds	
Date	Latitude (N)	Longitude (W)	Buoy Number	Drogue Depth (m)	Days Tracked	Total Distance Travelled (km)	Average Speed (cm/sec)	Direction (°t)	Speed (cm/sec)	From (°t)	Speed (m/sec)
May 5, 1977	29°00.0'	94°49.5'	014	1	1	19.5	23.6	340	23.5	180	6.0
"	29°00.0'	94°49.5'	016	10	2	32.4	18.0	237	6.5	180	5.5
"	28°52.0'	94°41.5'	017	1	2	43.5	24.9	253	15.7	180	5.5
"	28°52.0'	94°41.5'	015	10	0	No Signals Received					
"	28°44.7'	94°34.6'	013	1	0	No Signals Received					
"	28°44.7'	94°34.6'	012	10	2	29.6	17.5	311	3.6	180	5.5
Jun 17, 1977	29°00.0'	94°49.5'	031	1	3	100.1	33.1	062	33.0	180	6.2
"	29°00.0'	94°49.5'	025	10	4	117.5	30.5	035	15.2	180	6.3
Jun 18, 1977	28°52.0'	94°41.5'	020	1	2	56.0	26.8	061	26.6	180	6.2
"	28°52.0!	94°41.5'	011	1	1	16.7	11.9	063	11.9	180	6.2
"	28°52.0'	94°41.5'	019	1	4	106.5	28.2	051	17.2	180	6.3
"	28°52.0'	94°41.5'	028	10	0	No Signals Received					
"	28°44.7'	94°34.6'	030	1	6	126.9	23.3	035	9.6	180	6.3
"	28°44.7'	94°34.6'	029	10	0	No Signals Received					
"	28°44.7'	94°34.6'	027	10	6	95.4	17.6	053	2.2	180	6.3
Aug 1 1977	28°52.0'	94°41.5'	038	1	10	178.8	20.7	262	7.6	167	3.8
"	28°52.0'	94°41.5'	048	1	0	No Signals Received					
"	28°52.0'	94°41.5'	035	10	3	34.3	14.0	107	12.5	214	3.1
"	28°44.7'	94°34.6'	032	1	1	49.1	68.2	135	68.2	245	5.0
"	28°44.7'	94°34.6'	037	10	0	No Signals Received					
Aug 17, 1977	28°55.6'	94°41.1'	040	1	9	173.3	22.7	077	14.1	210	4.6
"	28°55.6'	94°41.1'	041	10	9	129.7	17.0	062	10.7	210	4.6
Aug 18, 1977	28°53.7'	94°44.3'	042	1	8	175.1	24.8	070	12.5	210	4.6
"	28°53.7'	94°44.3'	043	10	2	20.4	11.7	051	5.8	159	3.3
"	28°53.2'	94°38.6'	044	1	8	175.1	24.9	051	15.6	210	4.6
"	28°53.2'	94°38.6'	027	10	8	165.3	26.3	073	9.3	210	4.6
Nov 11, 1977	28°53.5'	94°42.6'	104	1	4	115.3	34.6	173	5.7	150	2.2
"	28°53.5'	94°42.6'	102	10	3	84.9	31.7	147	12.4	144	1.3
"	28°54.5'	94°42.6'	103	1	4	113.6	35.1	170	6.2	151	2.3
"	28°54.5'	94°42.6'	101	10	0	No Signals Received					
Feb 10, 1978	28°53.5'	94°42.6'	106	1	1	19.1	24.1	276	24.6	017	3.2
"	28°53.5'	94°42.6'	109	10	2	35.4	21.9	259	20.9	030	5.1
"	28°53.5'	94°43.8'	061	1	3	64.5	27.1	250	25.3	092	2.2
"	28°53.5'	94°43.8'	107	10	1	22.4	24.9	263	23.1	061	4.2
Apr 25, 1978	29°00.0'	94°49.5'	134	1	0	No Signals Received					
"	29°00.0'	94°49.5'	130	10	7	162.9	26.2	215	21.5	167	3.4
"	28°53.2'	94°41.0'	050	1	8	173.6	24.1	249	19.3	151	2.4
"	28°53.2'	94°41.0'	125	10	8	150.3	20.8	236	16.3	151	2.4
"	28°44.7'	94°34.6'	105	1	0	No Signals Received					
"	28°44.7'	94°34.6'	123	10	8	194.4	27.1	232	16.9	151	2.5

Table 4. Dye experiment results, growth rates and movements of dye plumes.

Experiment	Total Time Tracked (hours)	Growth rates (m/hr)			Ratio of Rates (Length/Width)	Depth of Penetration (m)	Plume Movement		Winds
		Length	Width	Equivalent Radius			Direction	Speed (m/hr)	
Summer (August 17, 1977)	3 1/4	245	35	60 (1) 30 (2) 55 (3)	7.0	5	North	190 (1) 595 (3)	2-5 m/sec from South
Fall (November 11, 1977)	3 1/2	95	45	25 (1) 8 (2) 20 (3)	2.1	7	North	225 (1) 730 (3)	2-4 m/sec from North
Winter (February 10, 1978)	2 3/4	70	60	30 (1)	1.2	10	West	440 (1)	3-4 m/sec from North

(1) During ebbing (offshore) tidal current
(2) During slack tidal current
(3) During flooding (onshore) tidal current
- Tidal currents from NOS/NOAA predictions for Galveston Bay Entrance (U.S. Dept. Commerce 1976b, 1977f)

Table 5. Percentage distribution by coastline ordinates of drifting buoy movements and local winds during buoy drift. (Daily winds from Galveston Weather Station, reported by prevailing octant.)

Season	Direction				Number of Values
	Onshore (to 285°-14°)	Upcoast (to 15°-104°)	Offshore (to 105°-194°)	Downcoast (to 195°-284°)	
Daily Buoy Movements:					
Summer	22%	43%	27%	9%	124 observations
Winter	18	12	21	49	94
Transitional	29	7	18	45	97
All	23	23	22	32	315
Resultant Buoy Movements (buoys tracked > 48 hours):					
Summer	0%	70%	25%	5%	20 buoys
Winter	0	7	20	73	15
Transitional	22	0	14	64	14
All	6	31	20	43	49
Daily Prevailing Winds During Buoy Drift:					
	(from S & SE)	(from W & SW)	(from N & NW)	(from E & NE)	
Summer	65%	31%	0%	4%	48 days
Winter	31	10	26	33	42
Transitional	55	10	25	10	40
All	51	18	16	15	130

Table 6. Seasonal comparisons of speed of buoy movements and local winds during buoy drift. (Winds from daily averages of Galveston Weather Station.)

Season	Speed Statistics				
	Average	Lowest 1/3	Median	Highest 1/3	Number of Values
Daily Buoy Speeds:					
Summer	26 cm/sec	<13 cm/sec	20 cm/sec	> 29 cm/sec	124 observations
Winter	23	<13	18	> 24	94
Transitional	20	< 8	15	> 21	97
All	23	<12	18	>25	315
Resultant Buoy Speeds (buoys tracked > 48 hours):					
Summer	14 cm/sec	< 10 cm/sec	11 cm/sec	>15 cm/sec	20 buoys
Winter	11	< 8	10	>12	15
Transitional	10	< 3	6	>14	14
All	12	<8	10	>13	49
Averaged Buoy Speeds (averages for each buoy tracked > 48 hours):					
Summer	22 cm/sec	< 18 cm/sec	21 cm/sec	>24 cm/sec	20 buoys
Winter	20	<13	16	>22	15
Transitional	17	< 9	15	>19	14
All	20	<15	18	>23	49
Daily Average Wind Speeds During Buoy Drift:					
Summer	5.3 m/sec	< 4.3 m/sec	4.8 m/sec	>5.4 m/sec	48 days
Winter	5.8	< 4.6	5.3	>5.9	42
Transitional	5.3	< 4.1	4.7	>5.4	40
All	5.4	< 4.3	4.9	>5.5	130
Resultants of Daily Average Wind Speeds During Buoy Drift:					
Summer	5.0 m/sec	< 4.4 m/sec	4.8 m/sec	>5.1 m/sec	20 buoys
Winter	2.0	< 1.3	1.5	>1.7	15
Transitional	2.8	<1.5	2.0	>2.5	14
All	3.5	<1.6	2.4	>4.3	49

Table 7. Principal and dominant periods of variability in anemometer and current meter records for mooring at Platform 288-A. Values derived from spectral energy diagrams of Part B.

Parameter	Principal Periods (days)						Dominant Periods (days)	
							Winter	Summer
Winds		1	2-4	6-8		14-21	3-4	7-8
4m current	13 hrs.	1	2-3	4-6	8-9	12-30	3.5	8.5
10m current	13 hrs.	1	2-4	5	7-12	>20	3.5	5 & 10.5
17.7m current	13 hrs.	1	2-3	4-6	8-9	>16	?	8.5

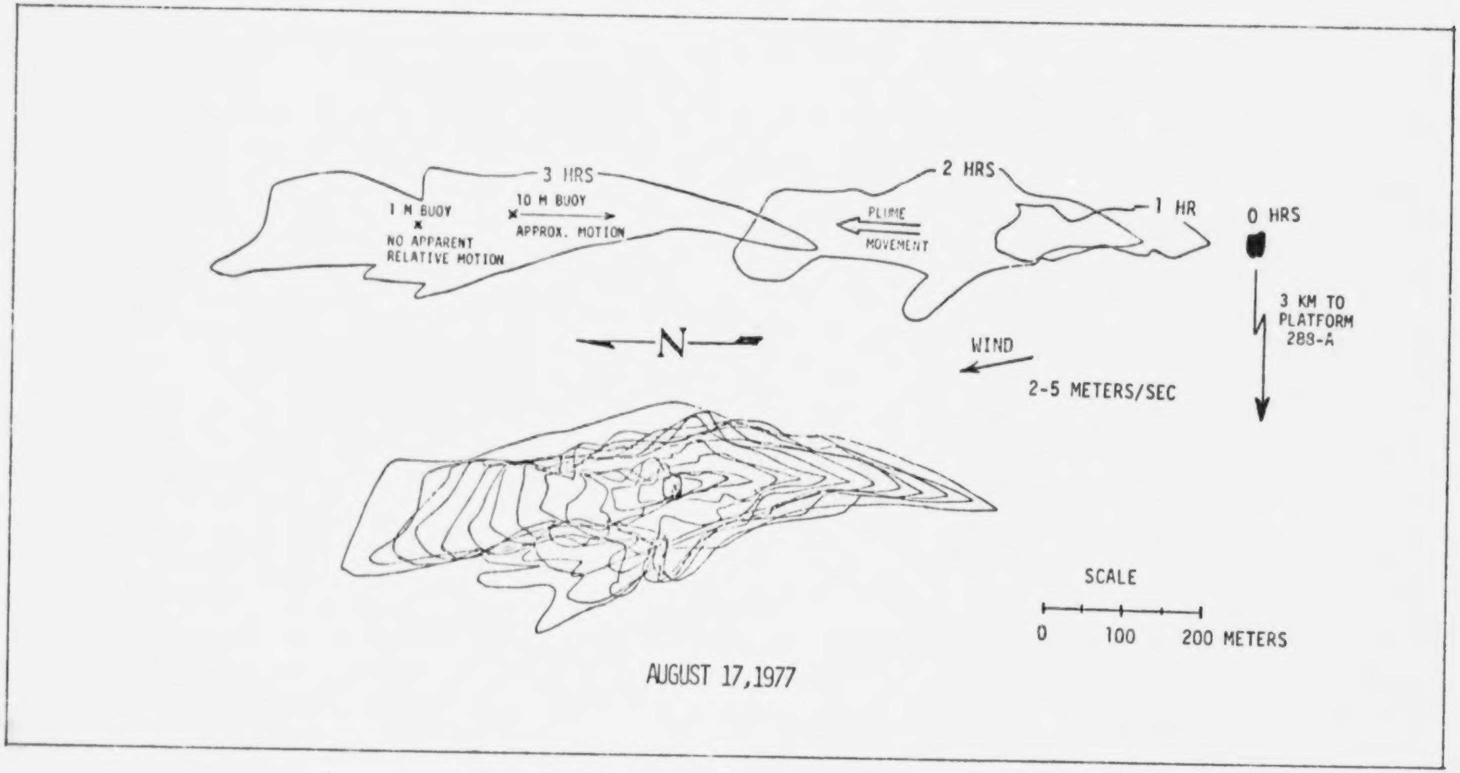

3 HRS
2 HRS
1 HR
0 HRS
1 M BUOY
NO APPARENT RELATIVE MOTION
10 M BUOY
APPROX. MOTION
PLUME MOVEMENT
3 KM TO PLATFORM 288-A
N
WIND
2-5 METERS/SEC
SCALE
0
100
200 METERS
AUGUST 17,1977

Figure 1a. Movement and spread of dye plume and movements of drifting buoys relative to the plume during summer dye experiment.

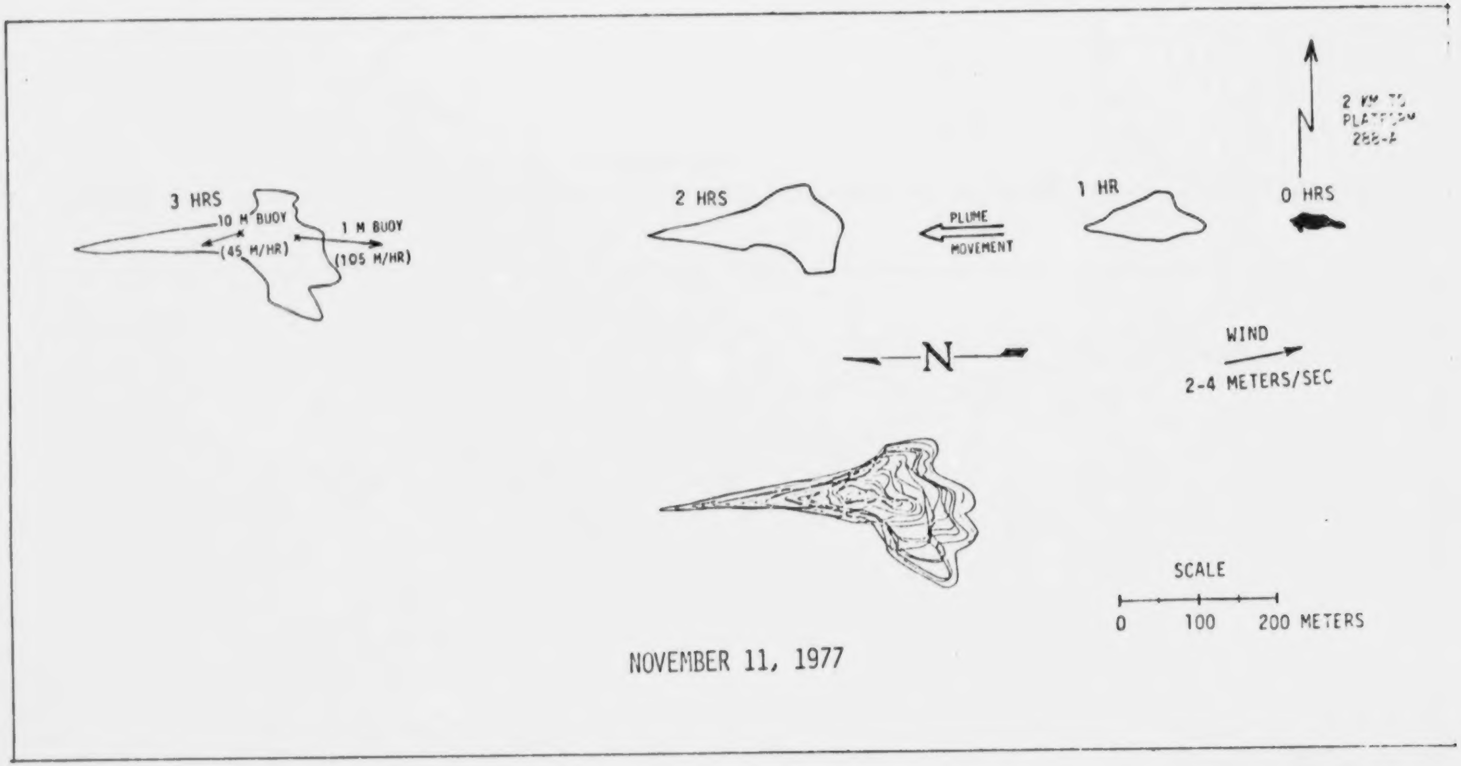

2 KM TO PLATFORM 288-A
0 HRS
1 HR
PLUME MOVEMENT
2 HRS
3 HRS
10 M BUOY
(45 M/HR)
1 M BUOY
(105 M/HR)
N
WIND
2-4 METERS/SEC
SCALE
0
100
200 METERS
NOVEMBER 11, 1977

Figure 1b. Movement and spread of dye plume and movements of drifting buoys relative to the plume during fall dye experiment.

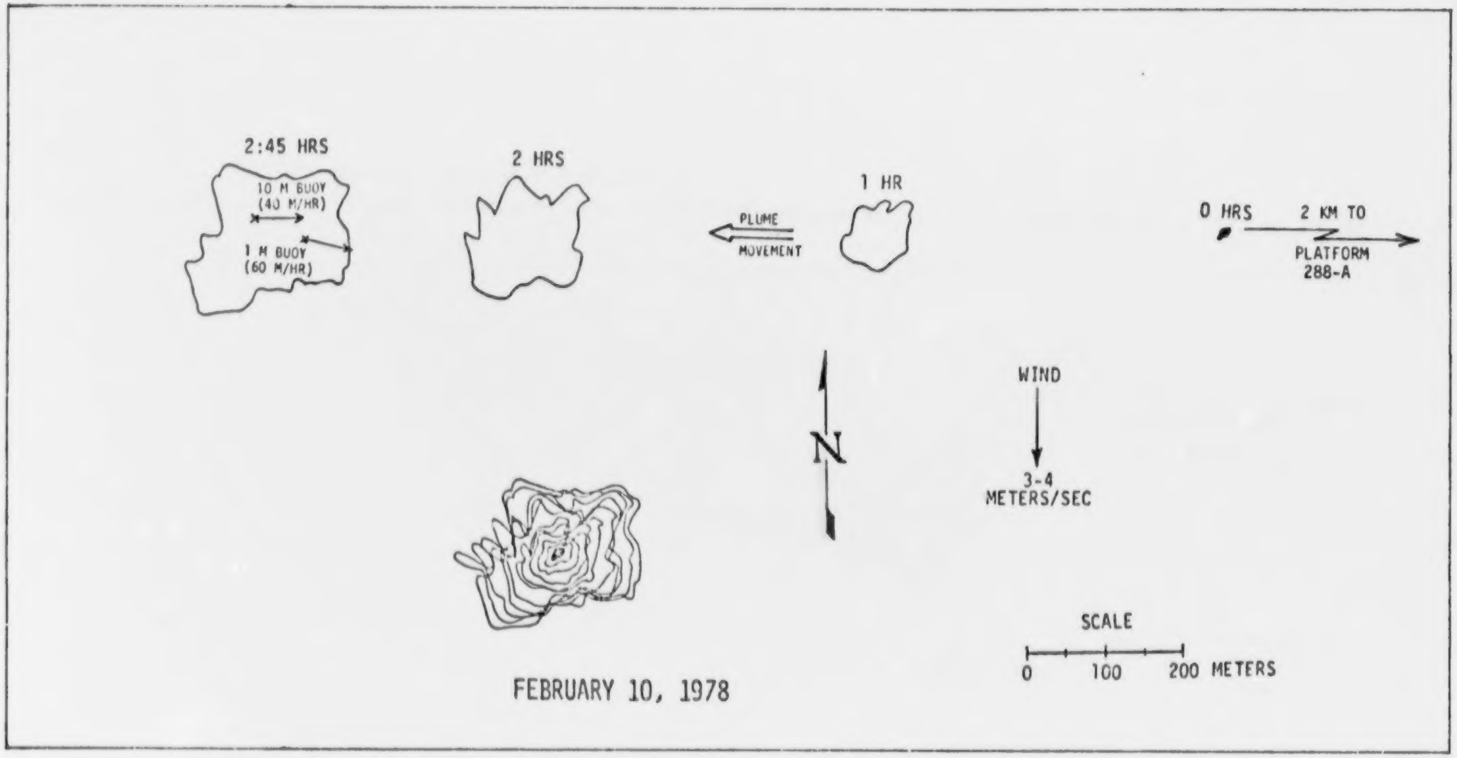

2:45 HRS
10 M BUOY
(40 M/HR)
1 M BUOY
(60 M/HR)
2 HRS
PLUME
MOVEMENT
1 HR
0 HRS
2 KM TO
PLATFORM
288-A
N
WIND
3-4
METERS/SEC
SCALE
0
100
200 METERS
FEBRUARY 10, 1978

Figure 1c. Movement and spread of dye plume and movements of drifting buoys relative to the plume during winter dye experiment.

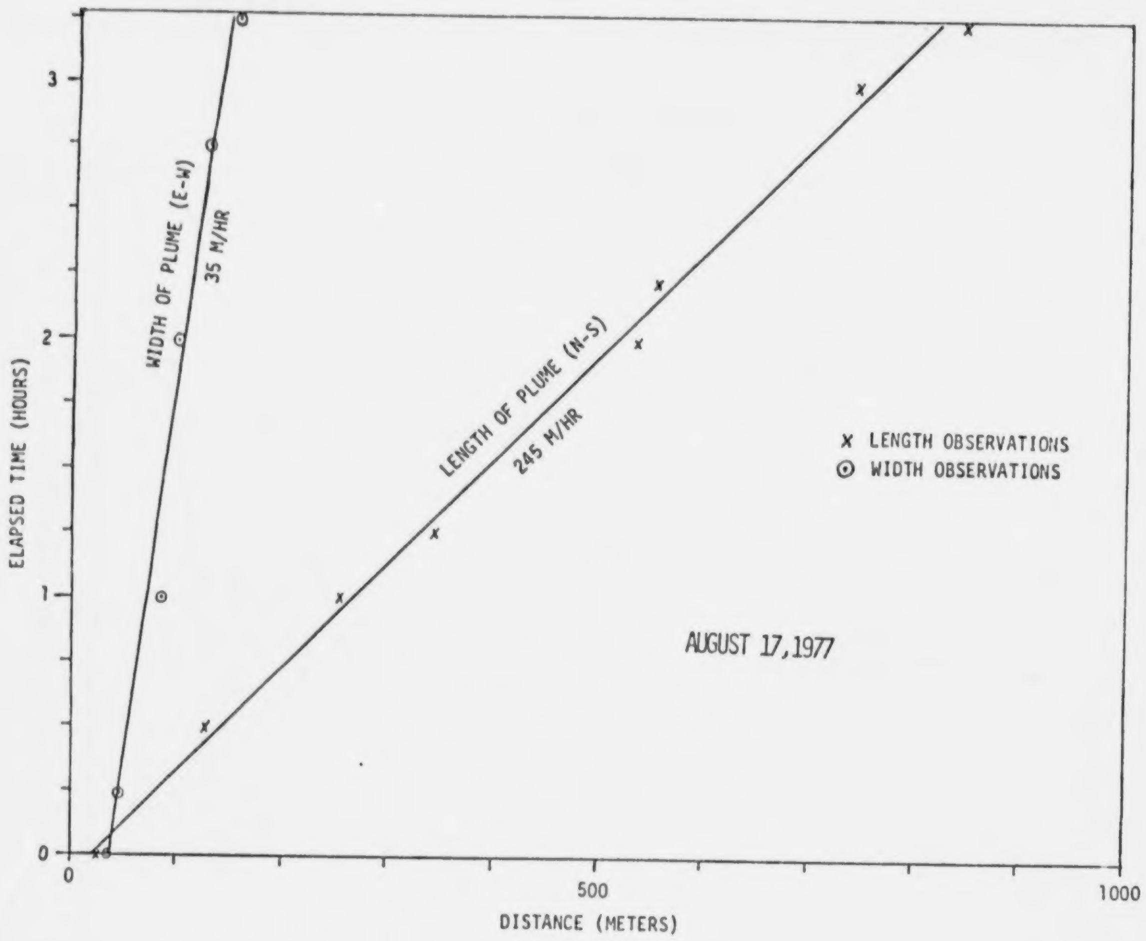


Figure 2a. Rates of spread of dye plume along principal axes during summer dye experiment.

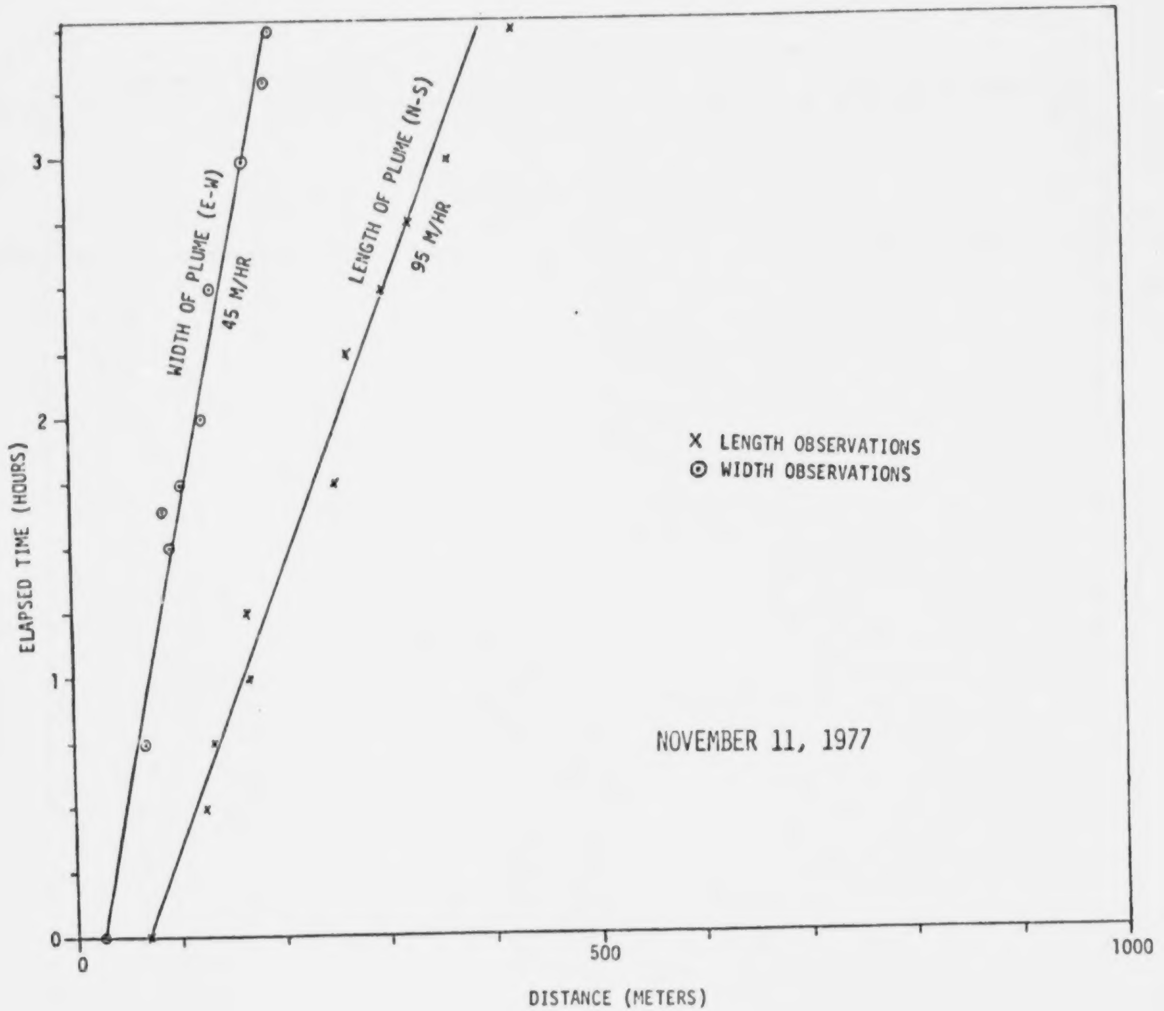


Figure 2b. Rates of spread of dye plume along principal axes during fall dye experiment.

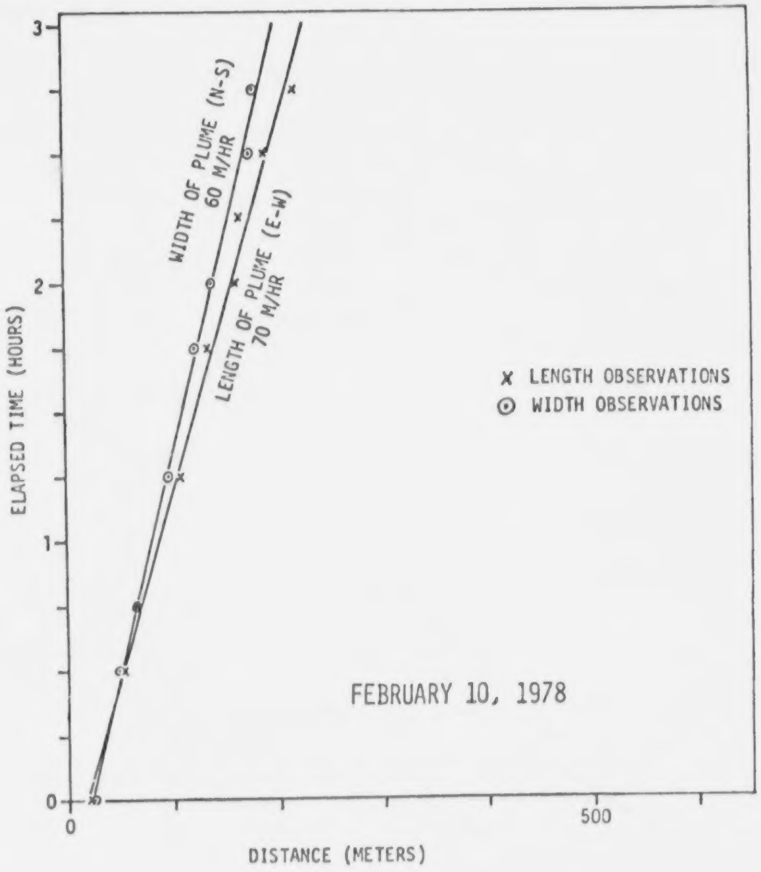


Figure 2c. Rates of spread of dye plume along principal axes during winter dye experiment.

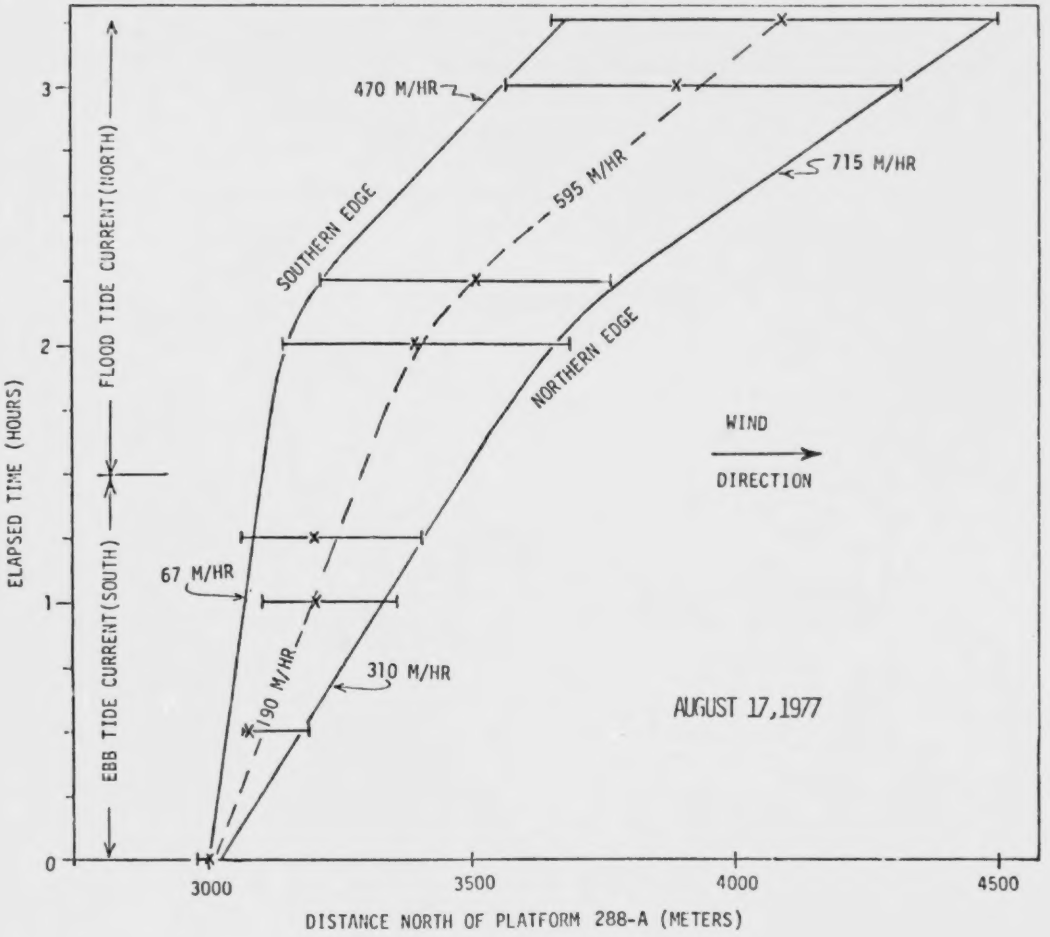


Figure 3a. Speed of movement of dye plume and correspondence to predicted tidal currents for Galveston Bay Entrance during summer dye experiment. (Tidal currents from U.S. Dept. Commerce, 1976b.)

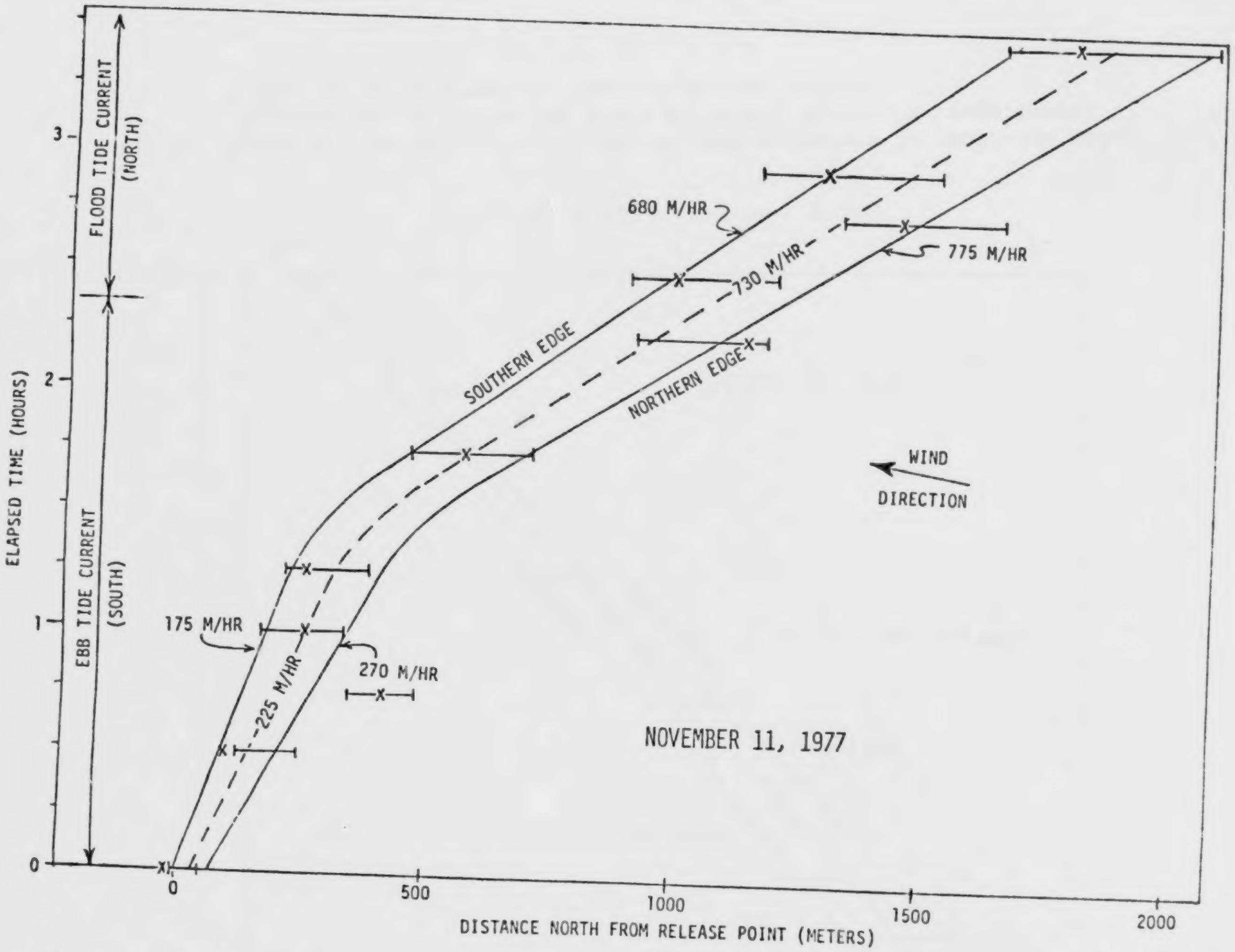


Figure 3b. Speed of movement of dye plume and correspondence to predicted tidal currents for Galveston Bay Entrance during fall dye experiment. (Tidal currents from U.S. Dept. Commerce, 1976b.)

]

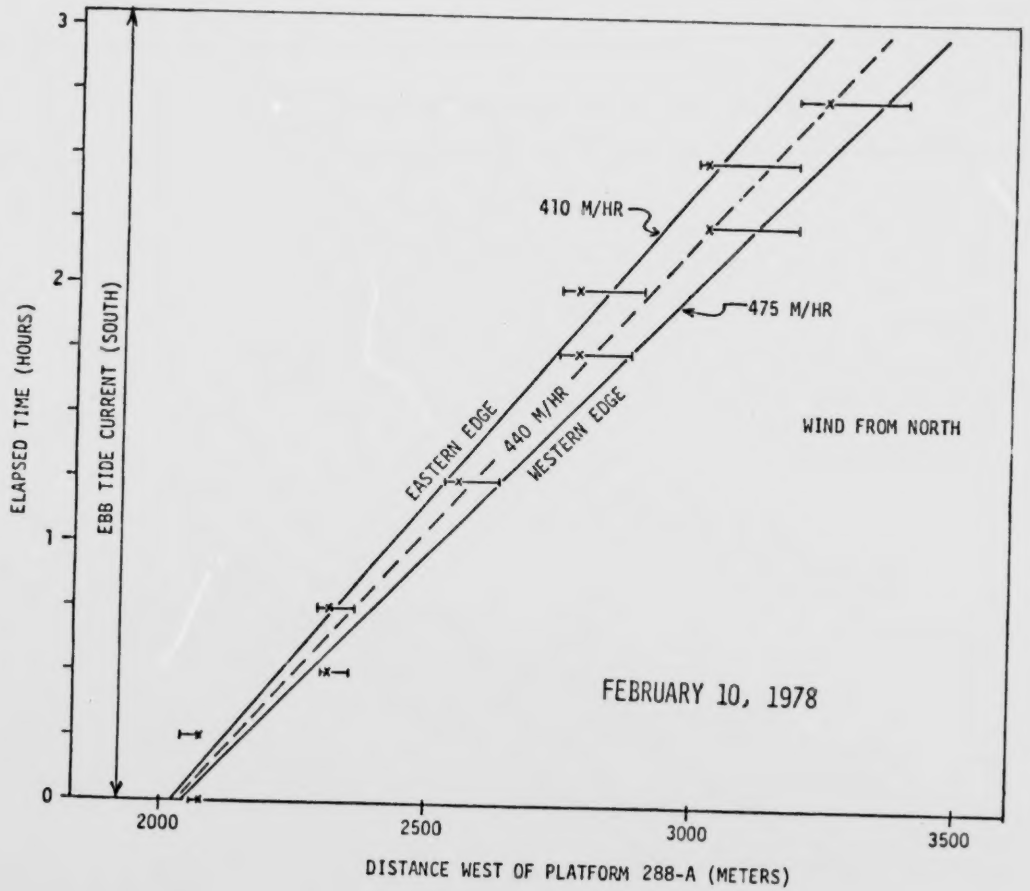


Figure 3c. Speed of movement of dye plume and correspondence to predicted tidal currents for Galveston Bay Entrance during winter dye experiment. (Tidal currents from U.S. Dept. Commerce, 1977f.)

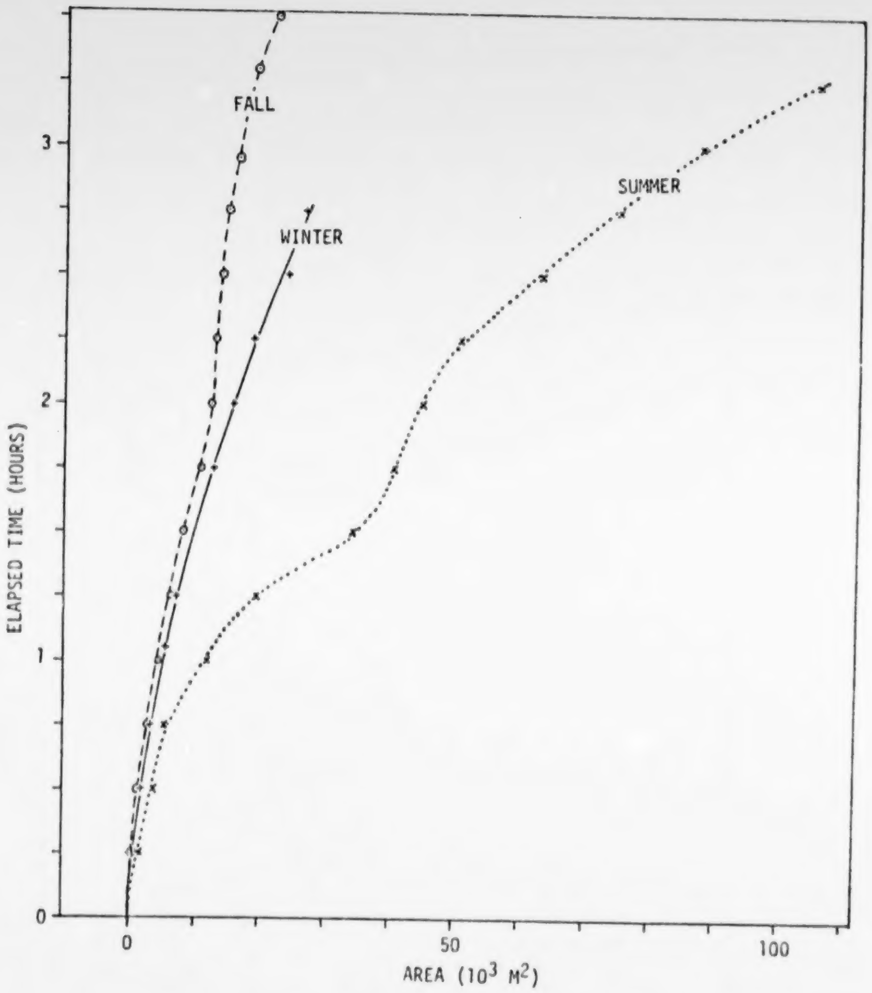


Figure 4. Comparison of areal growth of dye plumes during dye experiments.

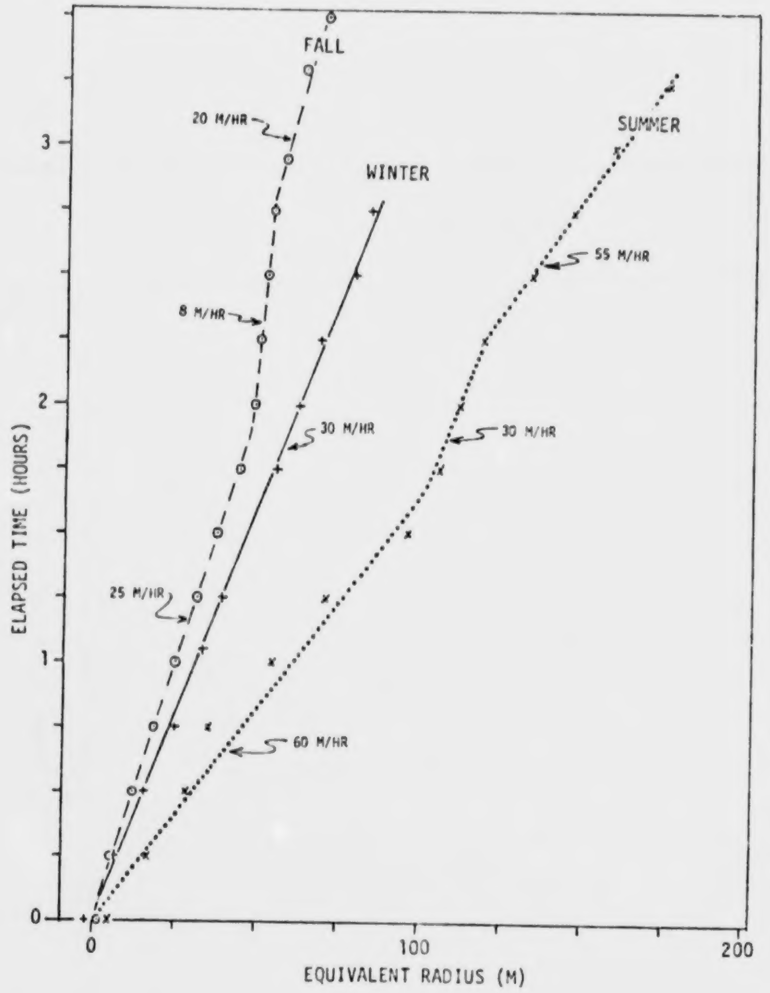


Figure 5. Comparison of rates of increase in equivalent radius during dye experiments.

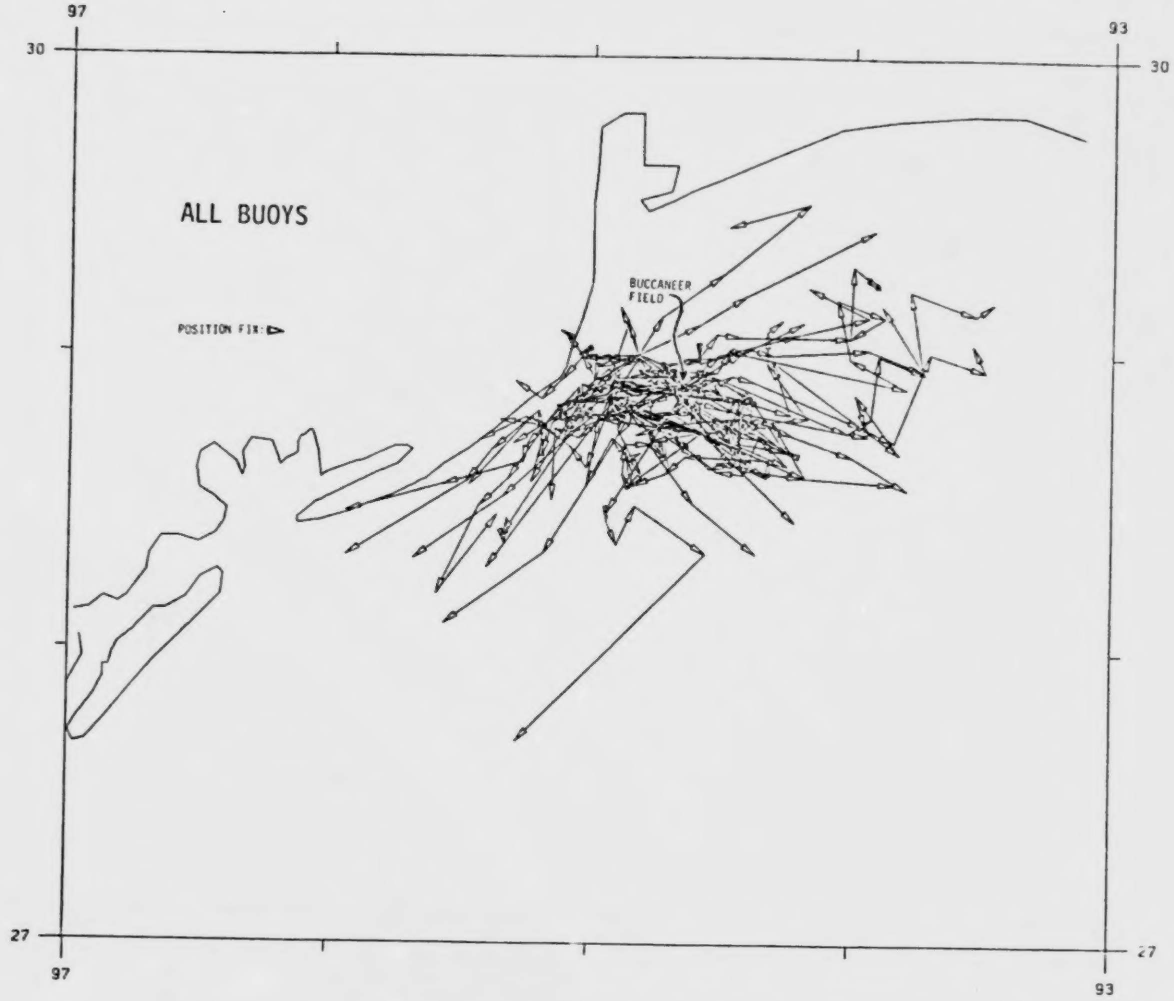

97
93
30
30
ALL BUOYS
BUCCANEER FIELD
POSITION FIX:
27
27
97
93

Figure 6. Movements of all drifting, transponding buoys deployed around the Buccaneer Field from July, 1976 through April, 1978.

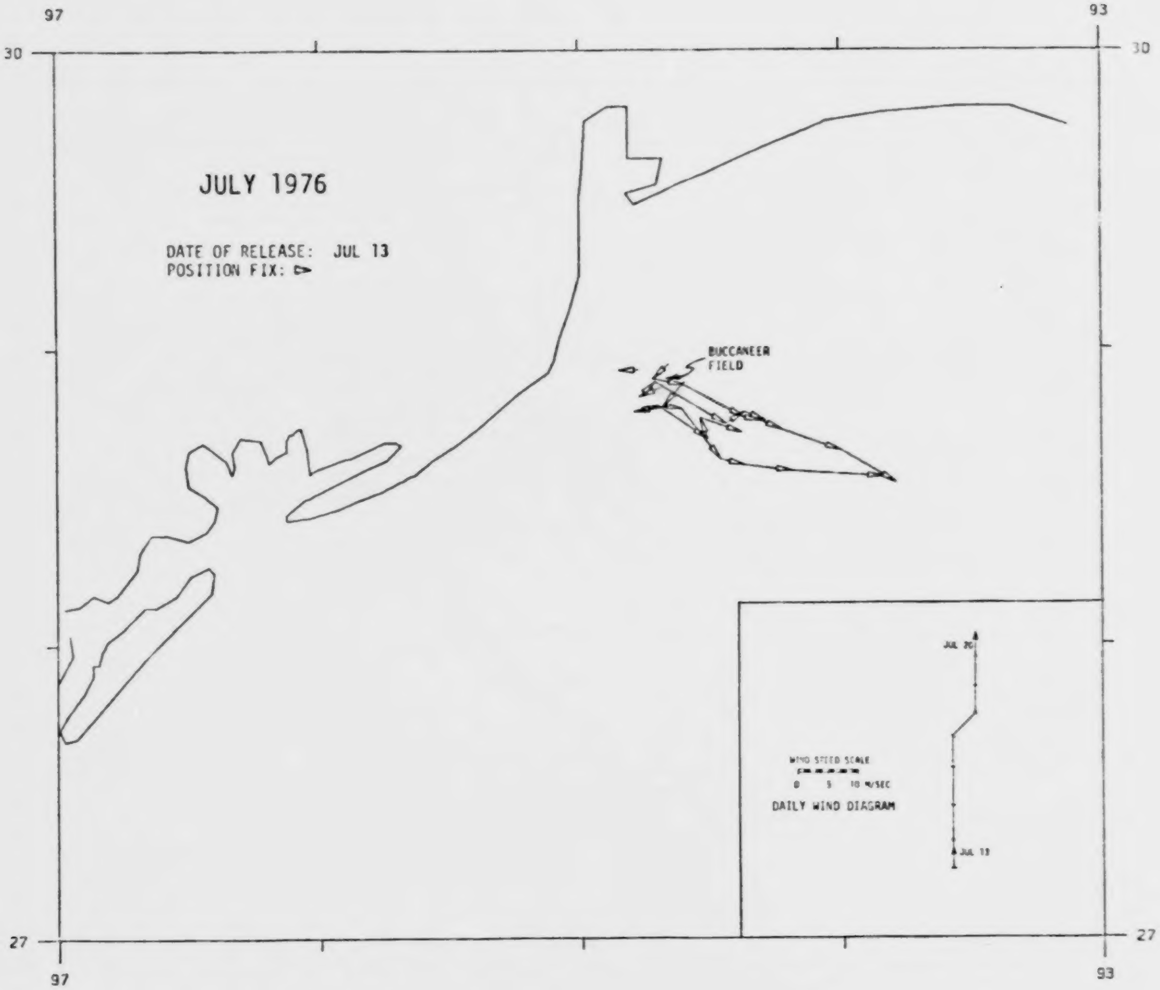

97
93
30
30
JULY 1976
DATE OF RELEASE: JUL 13
POSITION FIX: ▻
BUCCANEER FIELD
JUL 20
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
JUL 13
27
27
97
93

Figure 7. Movements of drifting, transponding buoys during July 13-20, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

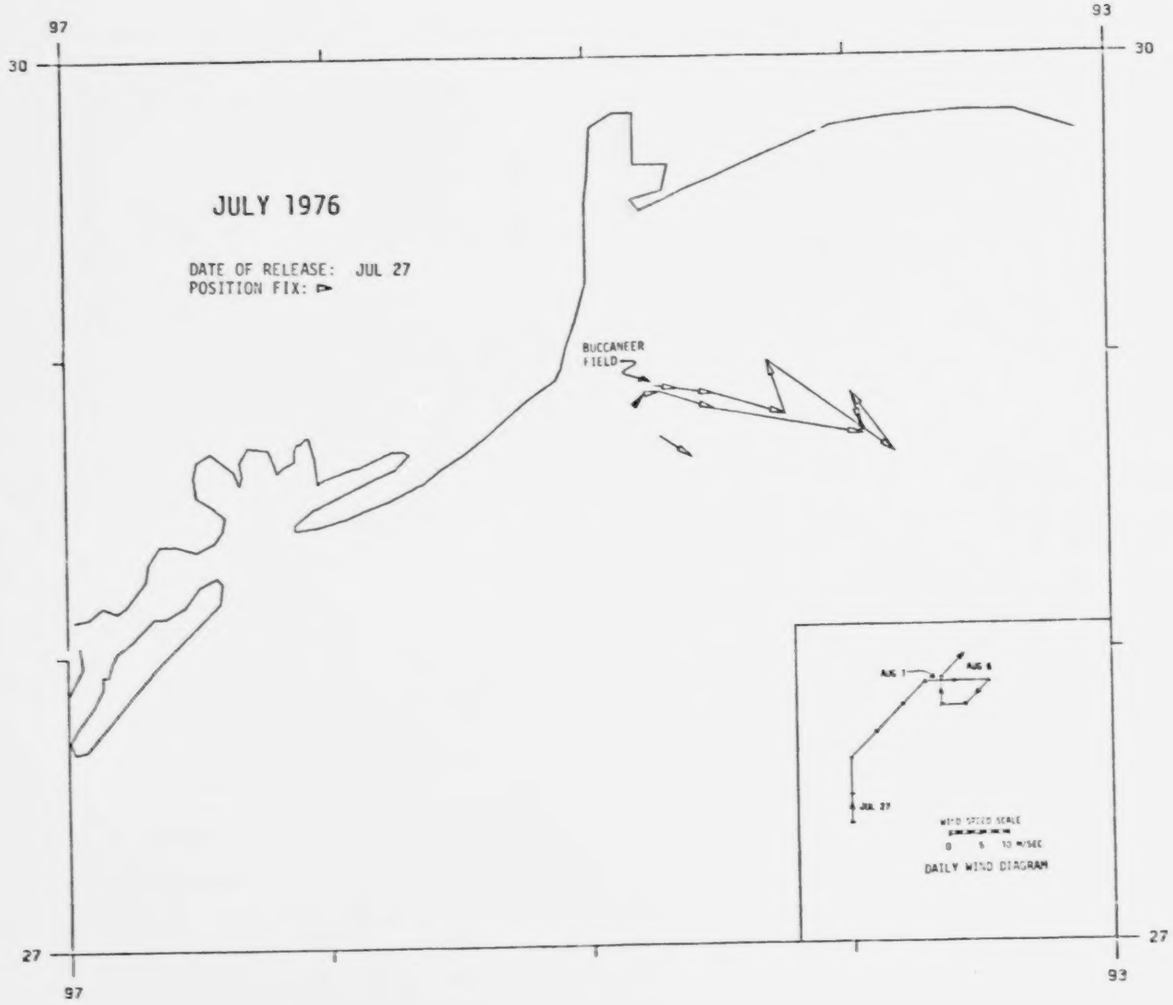

97
93
30
30
JULY 1976
DATE OF RELEASE: JUL 27
POSITION FIX: ▻
BUCCANEER FIELD
AUG 1
AUG 6
JUL 27
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 8. Movements of drifting, transponding buoys during July 27-August 6, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

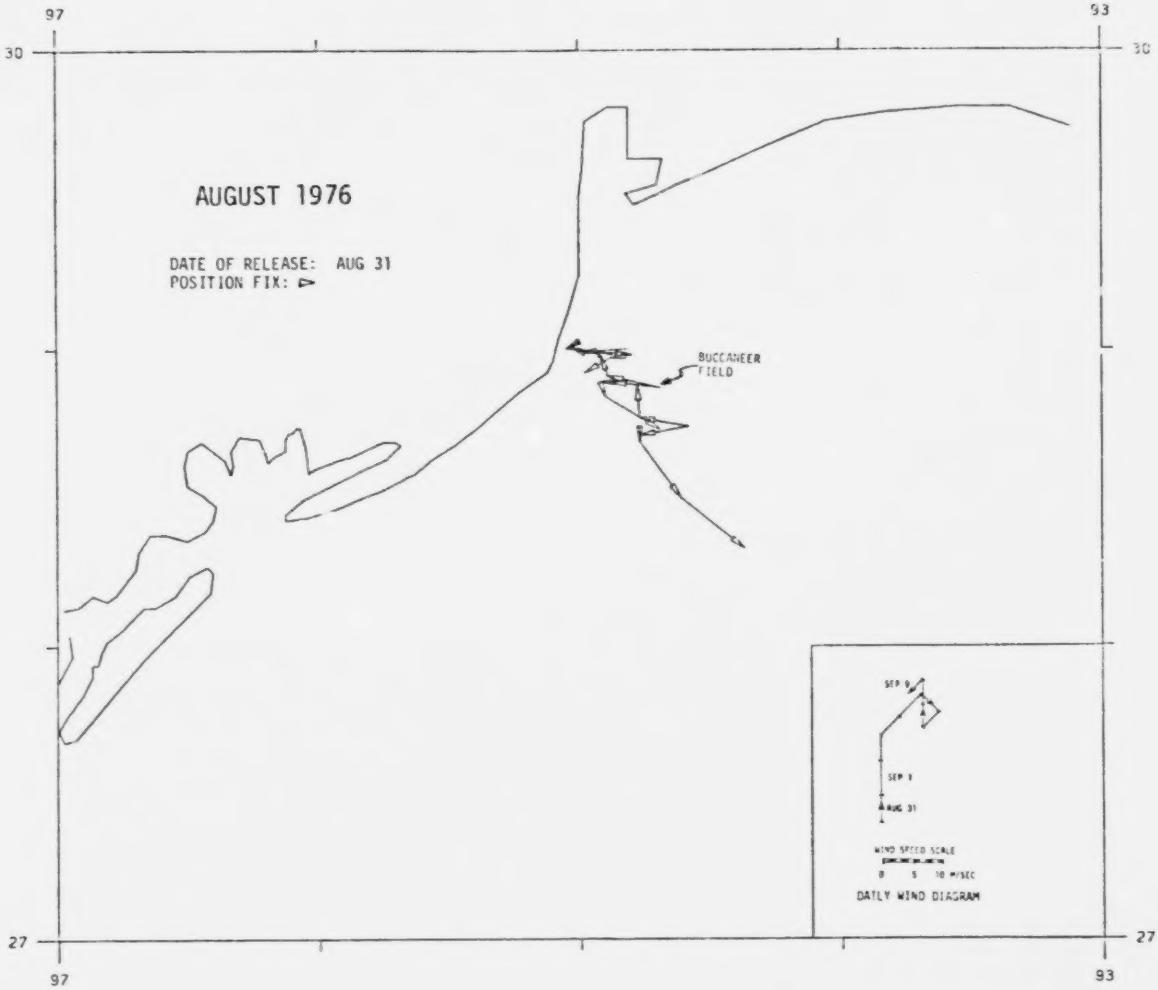

97
93
30
30
AUGUST 1976
DATE OF RELEASE: AUG 31
POSITION FIX: ▻
BUCCANEER FIELD
SEP 9
SEP 1
AUG 31
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 9. Movements of drifting, transponding buoys during August 31-September 9, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

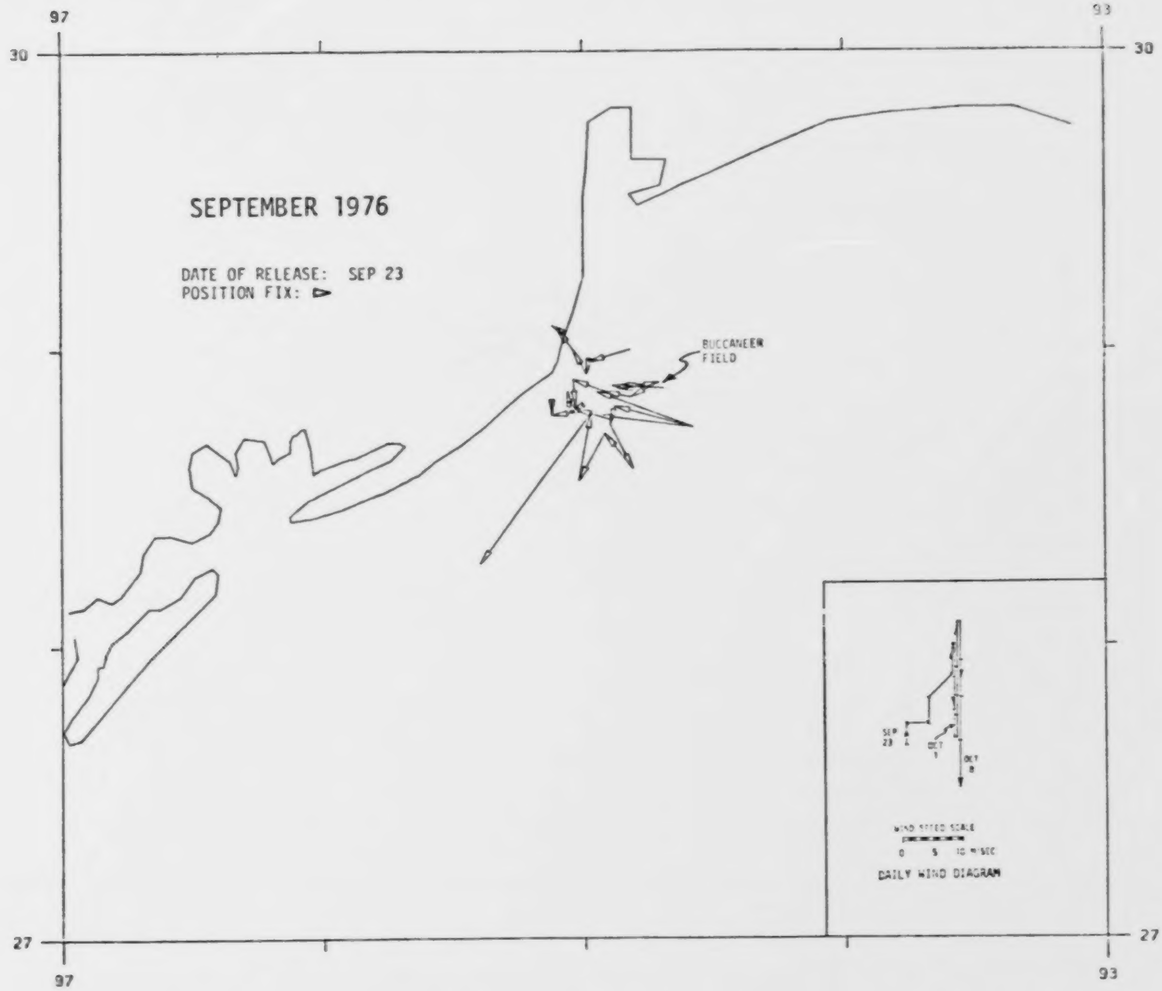

97
93
30
30
SEPTEMBER 1976
DATE OF RELEASE: SEP 23
POSITION FIX: ▻
BUCCANEER FIELD
SEP 23
OCT 1
OCT 8
WIND SPEED SCALE
0
5
10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 10. Movements of drifting, transponding buoys during September 23-October 8, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

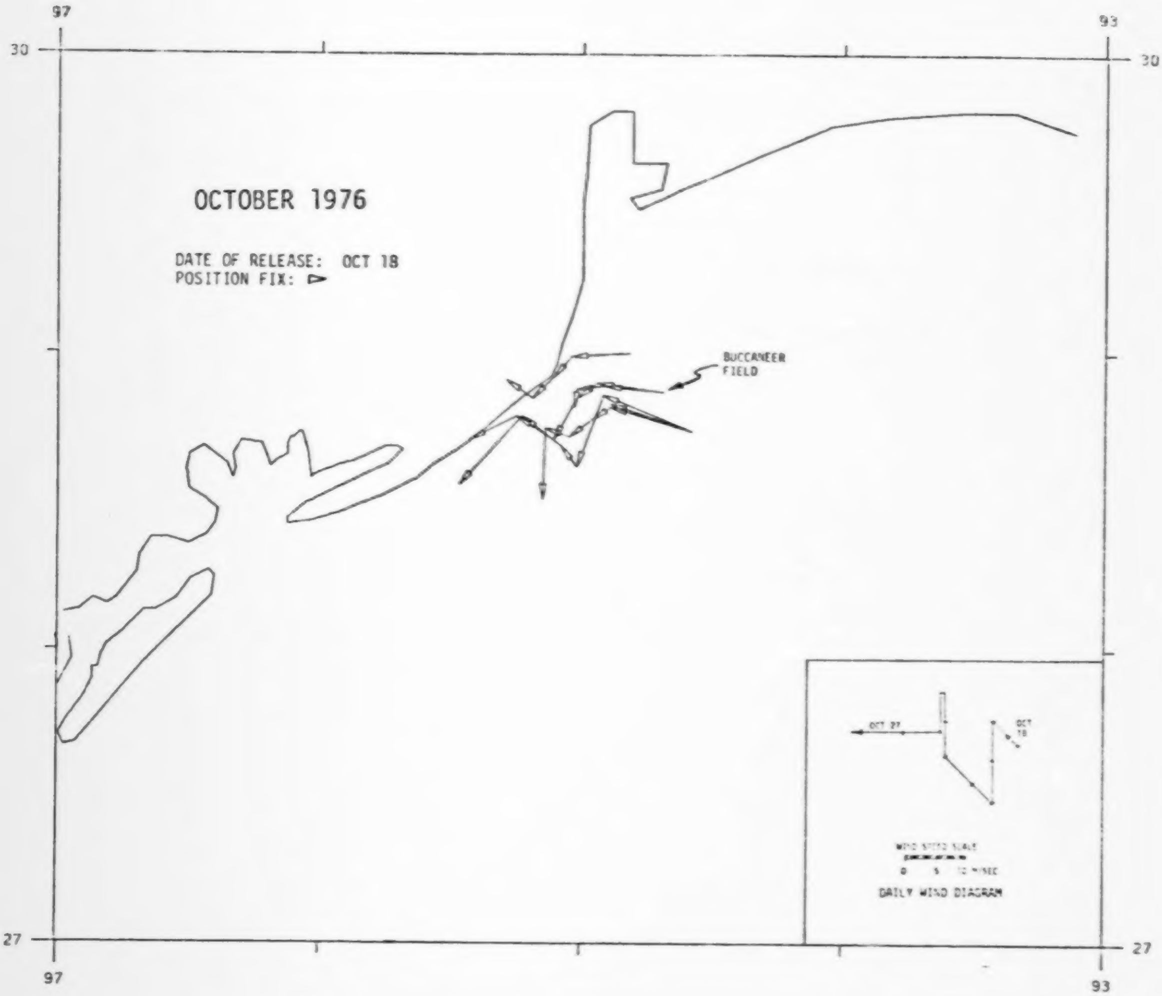
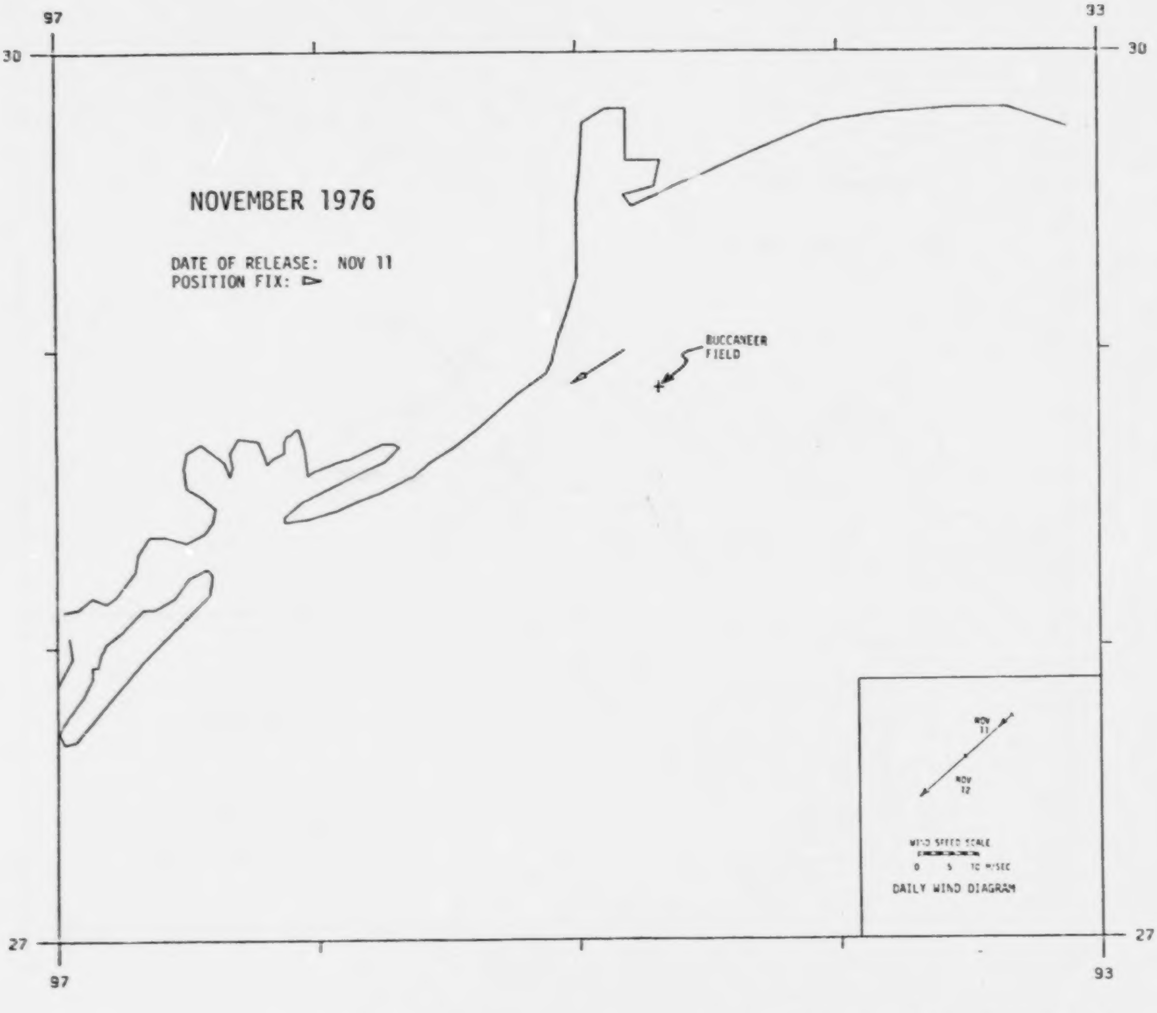

97
93
30
30
OCTOBER 1976
DATE OF RELEASE: OCT 18
POSITION FIX: ▷
BUCCANEER FIELD
OCT 27
OCT 18
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 11. Movements of drifting, transponding buoys during October 18-27, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)



97
93
30
30
NOVEMBER 1976
DATE OF RELEASE: NOV 11
POSITION FIX: ▻
BUCCANEER FIELD
NOV 11
NOV 12
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 12. Movement of drifting transponding buoy during November 11-12, 1976 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

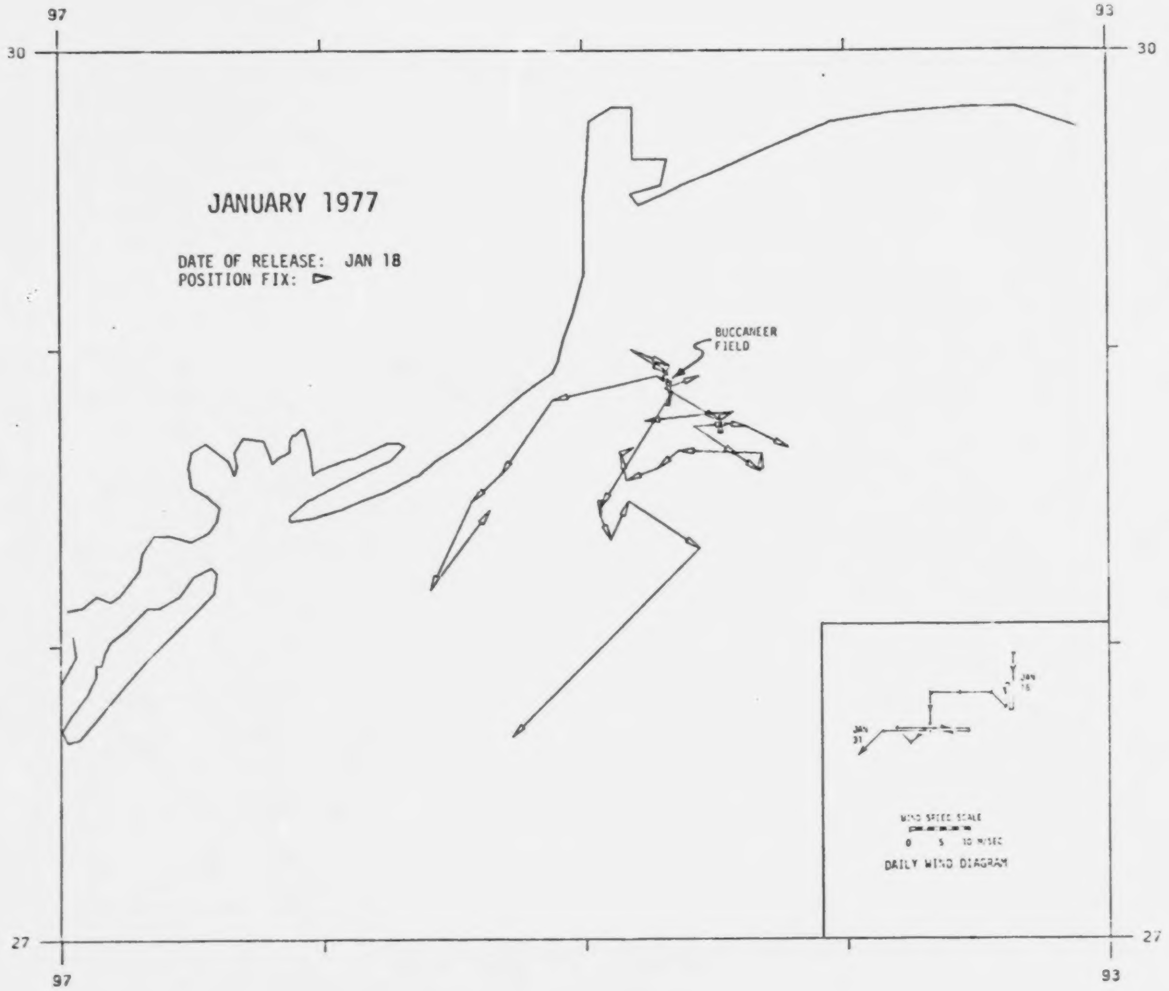

97
93
30
30
JANUARY 1977
DATE OF RELEASE: JAN 18
POSITION FIX: ▻
BUCCANEER FIELD
JAN 18
JAN 31
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 13. Movements of drifting, transponding buoys during January 18-31, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

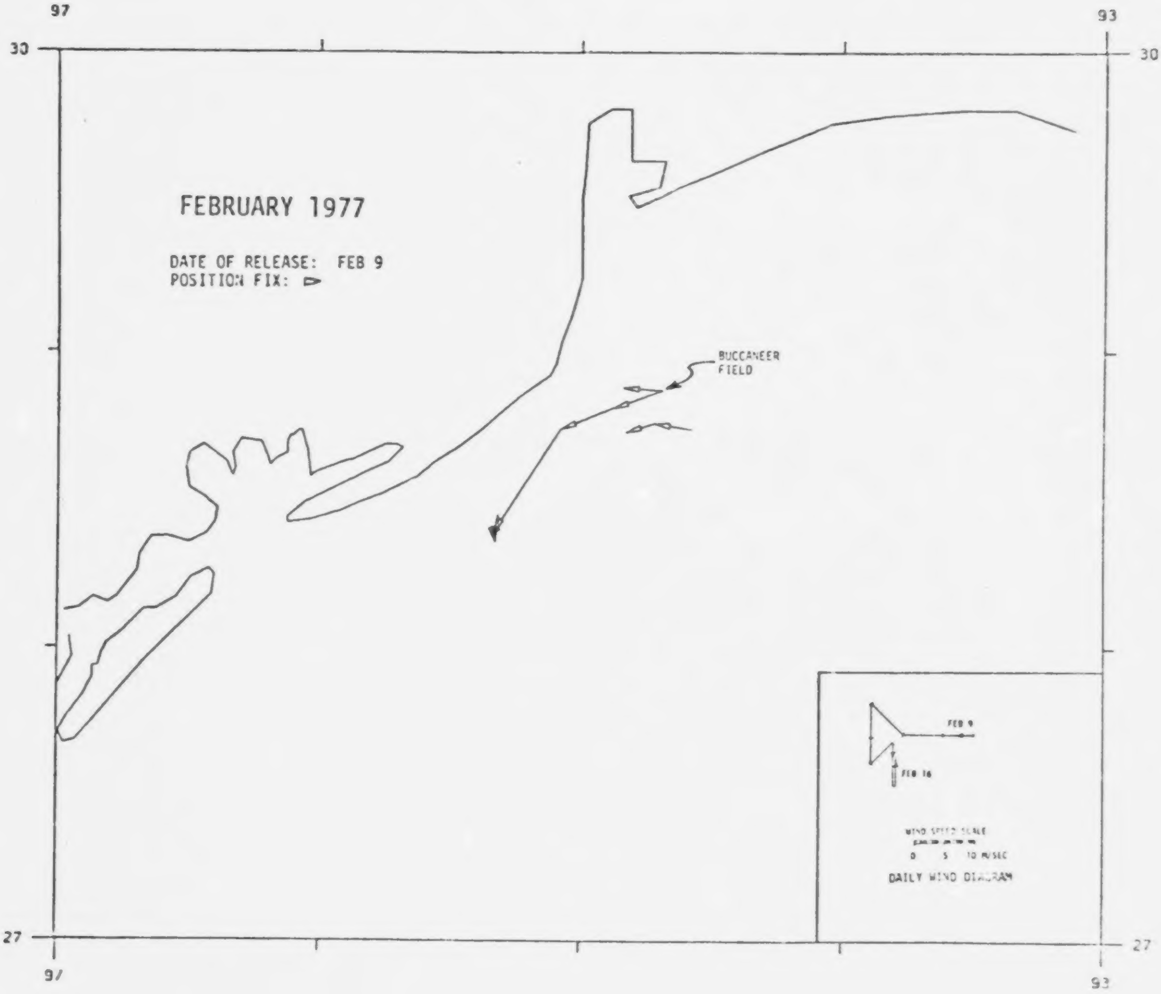

97
93
30
30
FEBRUARY 1977
DATE OF RELEASE: FEB 9
POSITION FIX: ▷
BUCCANEER FIELD
FEB 9
FEB 16
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 14. Movements of drifting, transponding buoys during February 9-16, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

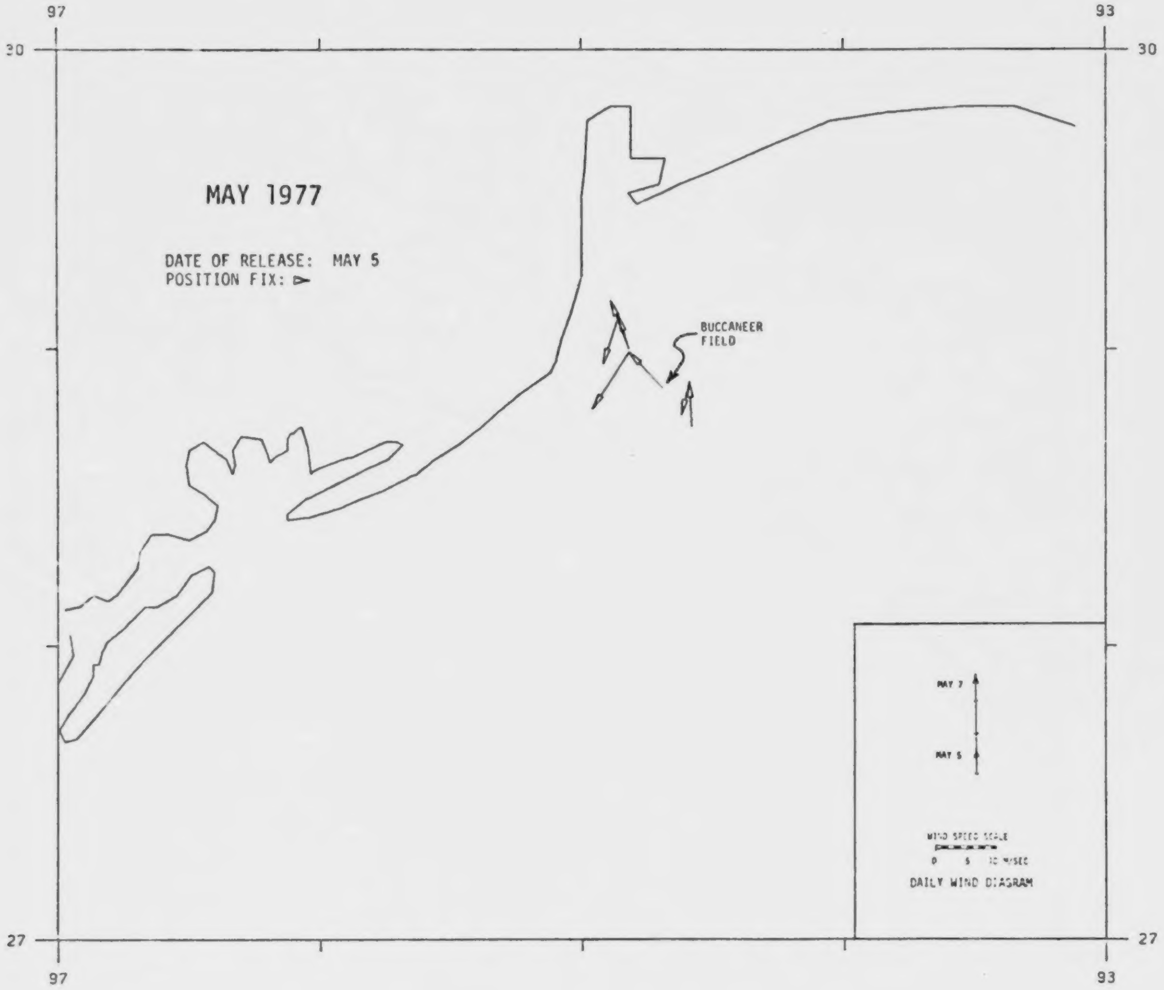

97
93
30
30
MAY 1977
DATE OF RELEASE: MAY 5
POSITION FIX:
BUCCANEER FIELD
MAY 7
MAY 5
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 15. Movements of drifting, transponding buoys during May 5-7, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

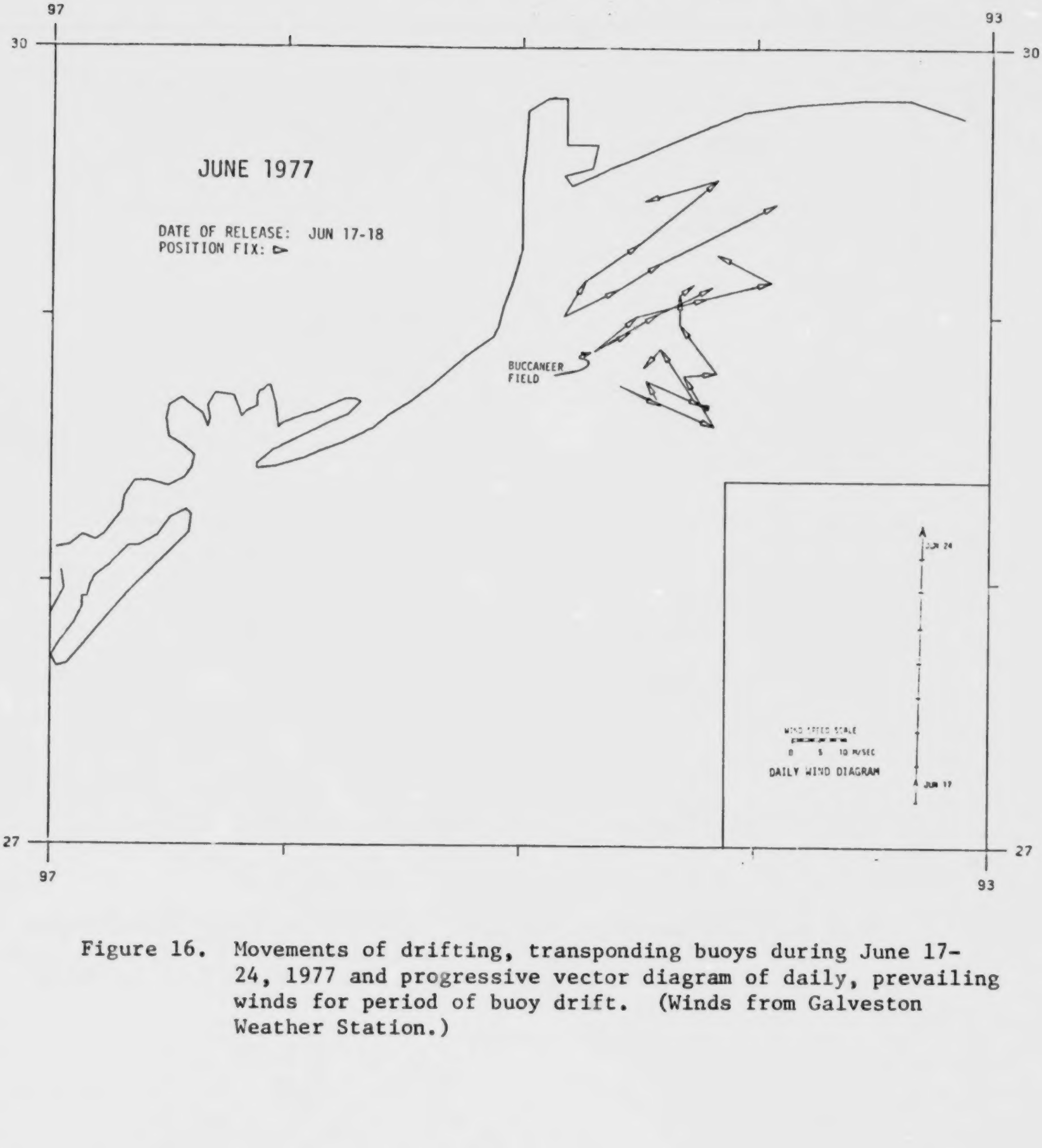

97
93
30
30
JUNE 1977
DATE OF RELEASE: JUN 17-18
POSITION FIX: ▻
BUCCANEER FIELD
JUN 24
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
JUN 17
27
27
97
93

Figure 16. Movements of drifting, transponding buoys during June 17-24, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

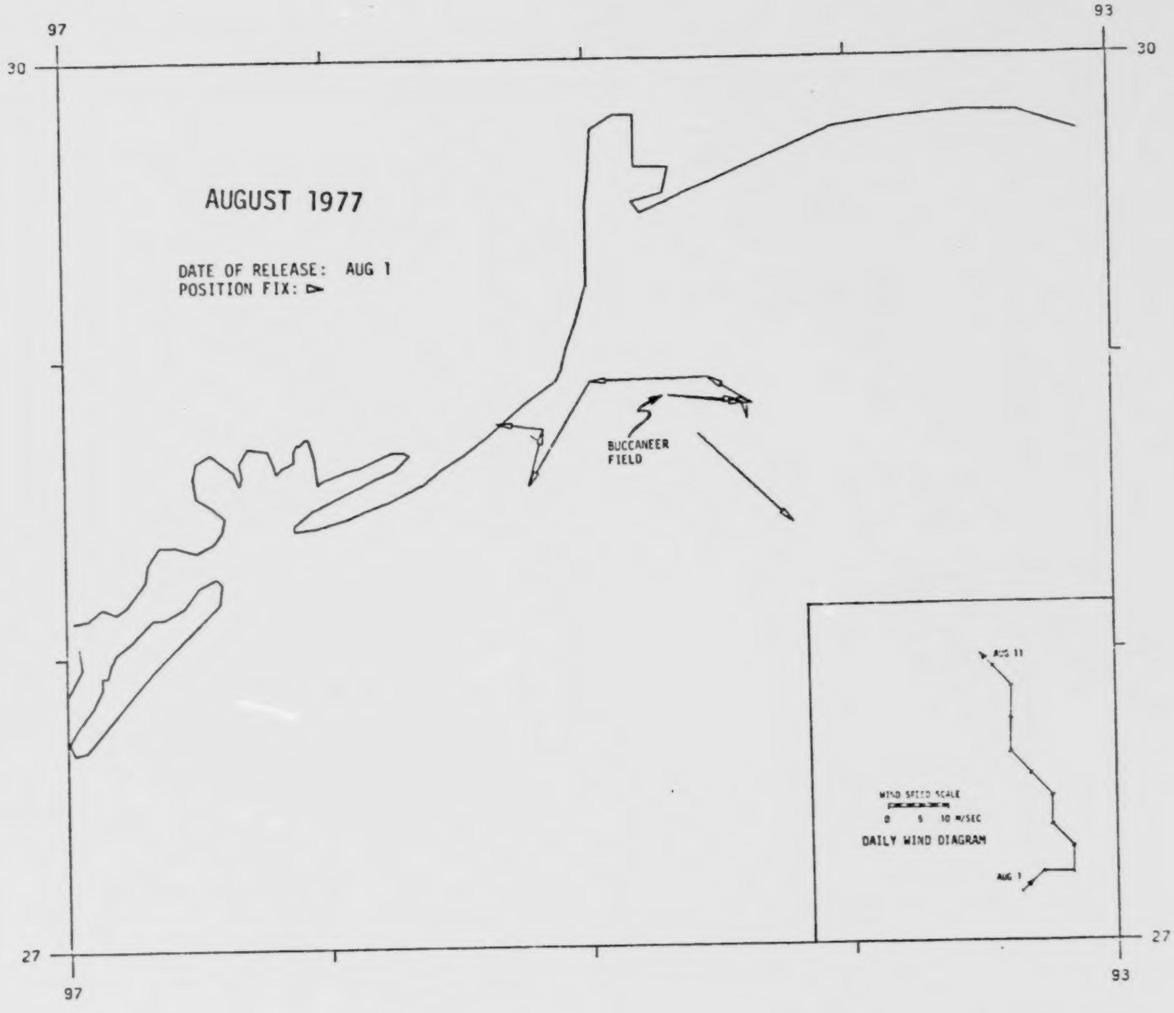

97
93
30
30
AUGUST 1977
DATE OF RELEASE: AUG 1
POSITION FIX: ▻
BUCCANEER FIELD
AUG 11
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
AUG 1
27
27
97
93

Figure 17. Movements of drifting, transponding buoys during August 1-11, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

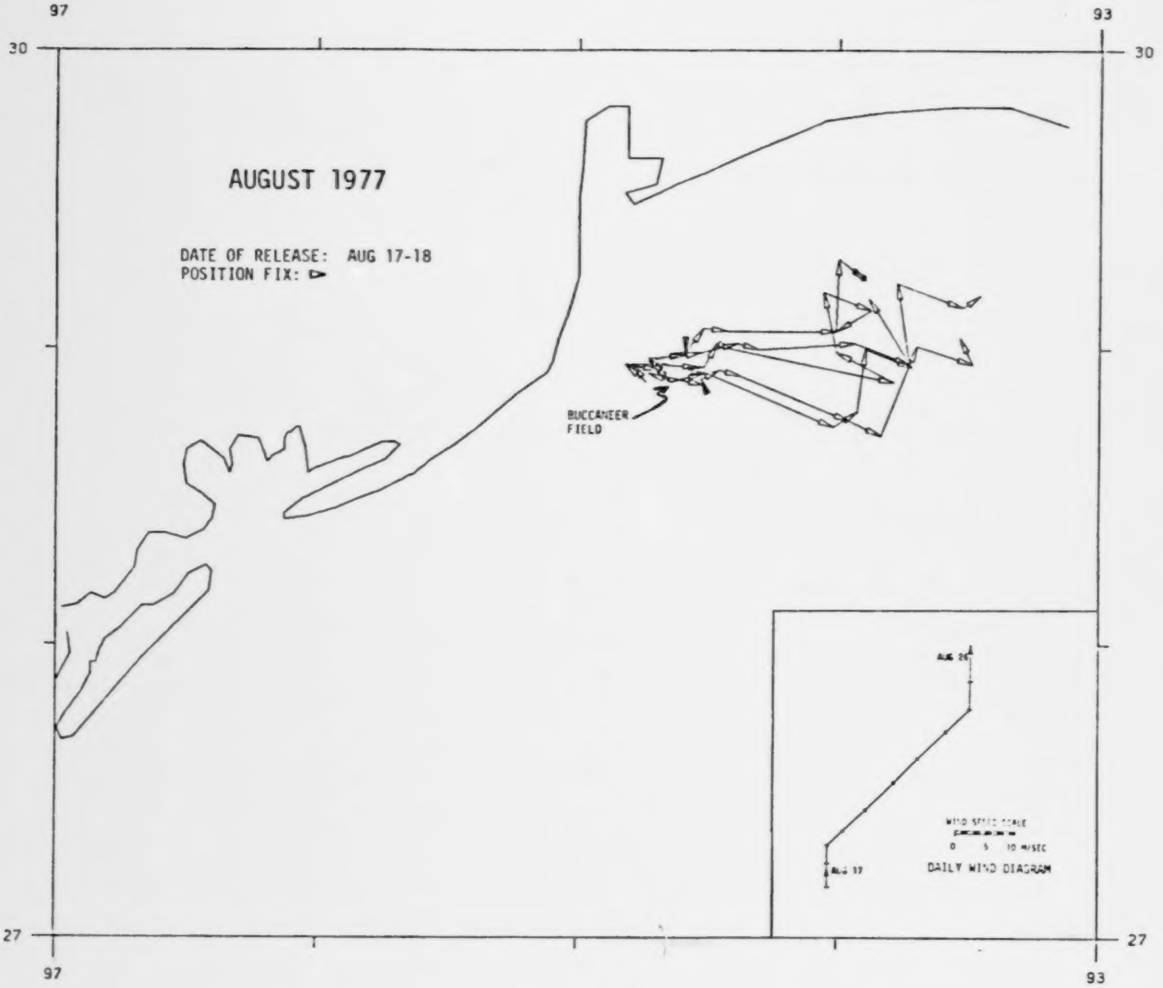

97
93
30
30
AUGUST 1977
DATE OF RELEASE: AUG 17-18
POSITION FIX:
BUCCANEER FIELD
AUG 26
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
AUG 17
27
27
97
93

Figure 18. Movements of drifting, transponding buoys during August 17-26, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

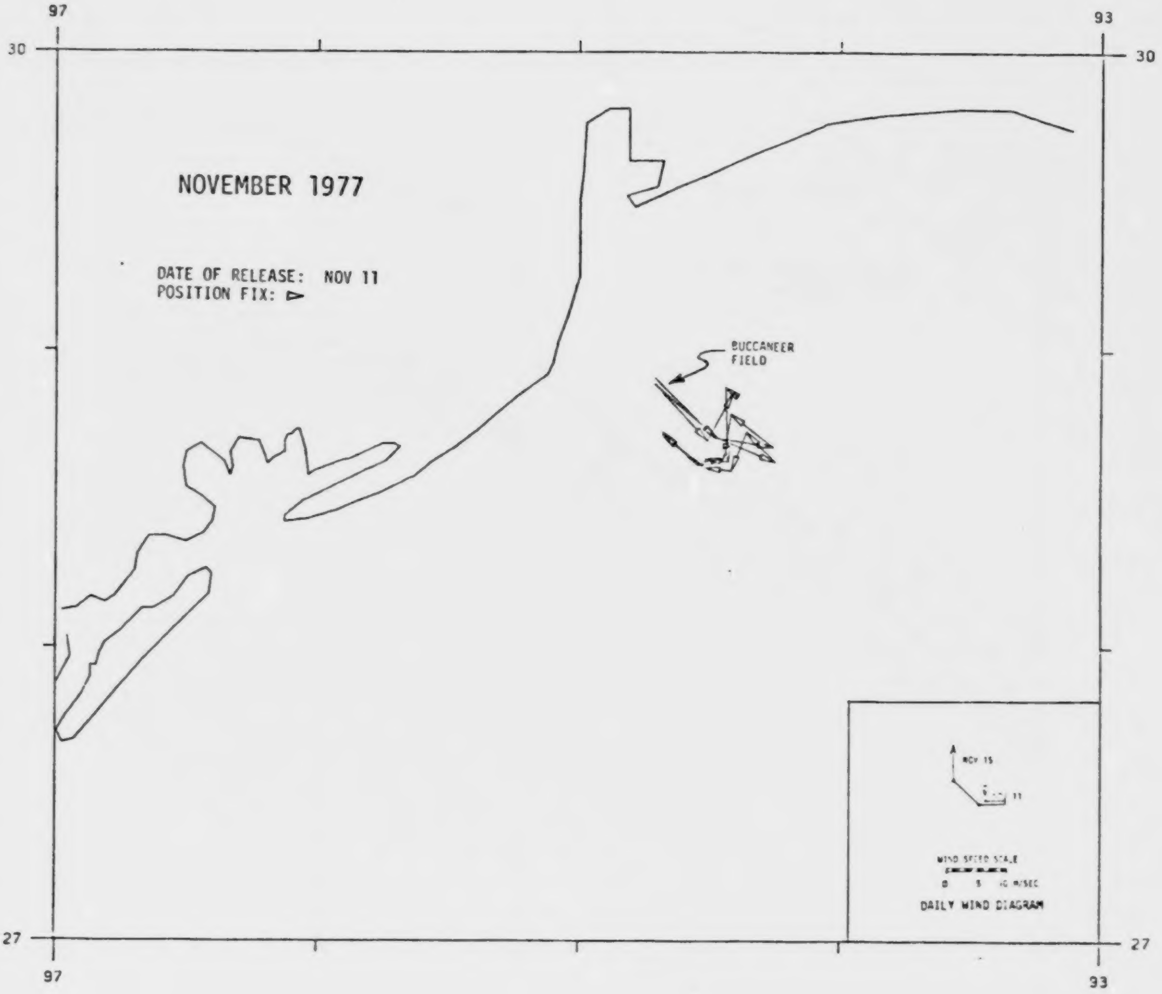

97
93
30
30
NOVEMBER 1977
DATE OF RELEASE: NOV 11
POSITION FIX: ⊳
BUCCANEER FIELD
NOV 15
11
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 19. Movements of drifting, transponding buoys during November 11-15, 1977 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

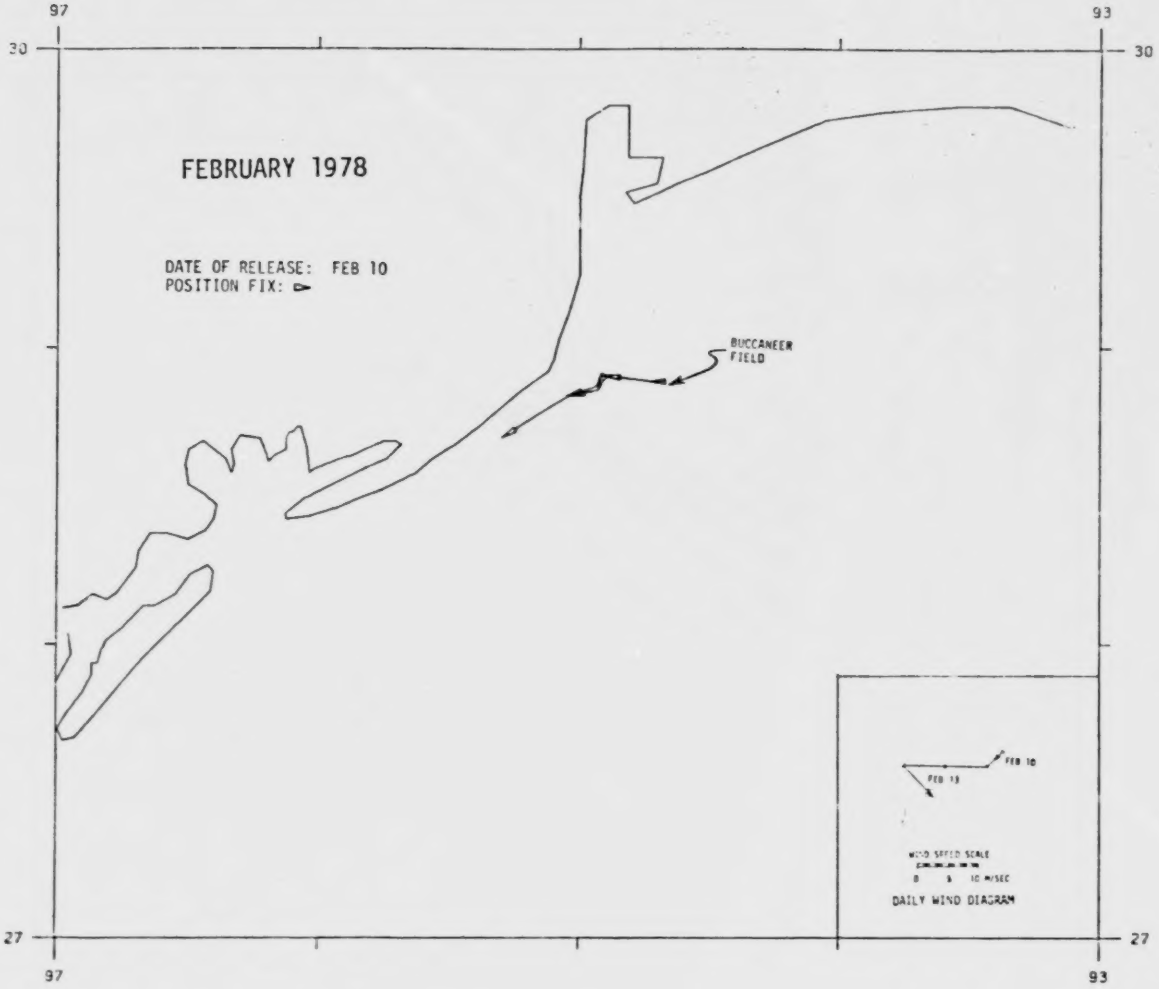

97
93
30
30
FEBRUARY 1978
DATE OF RELEASE: FEB 10
POSITION FIX:
BUCCANEER FIELD
FEB 10
FEB 13
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 20. Movements of drifting, transponding buoys during February 10-13, 1978 and progressive vector diagram of daily, prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

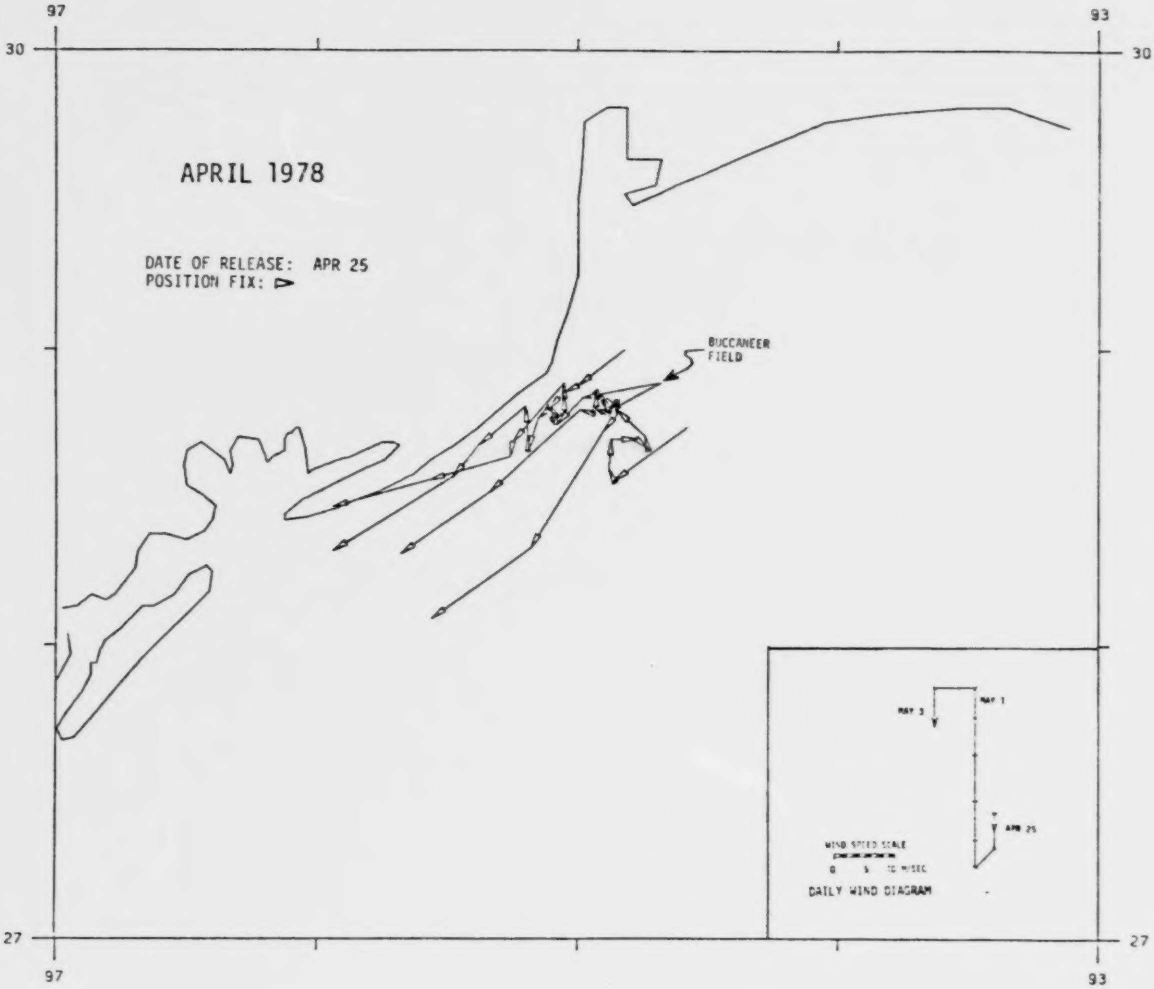

97
93
30
30
APRIL 1978
DATE OF RELEASE: APR 25
POSITION FIX: ▷
BUCCANEER FIELD
MAY 3
MAY 1
APR 25
WIND SPEED SCALE
0 5 10 M/SEC
DAILY WIND DIAGRAM
27
27
97
93

Figure 21. Movements of drifting, transponding buoys during April 25-May 3, 1978 and progressive vector diagram of daily prevailing winds for period of buoy drift. (Winds from Galveston Weather Station.)

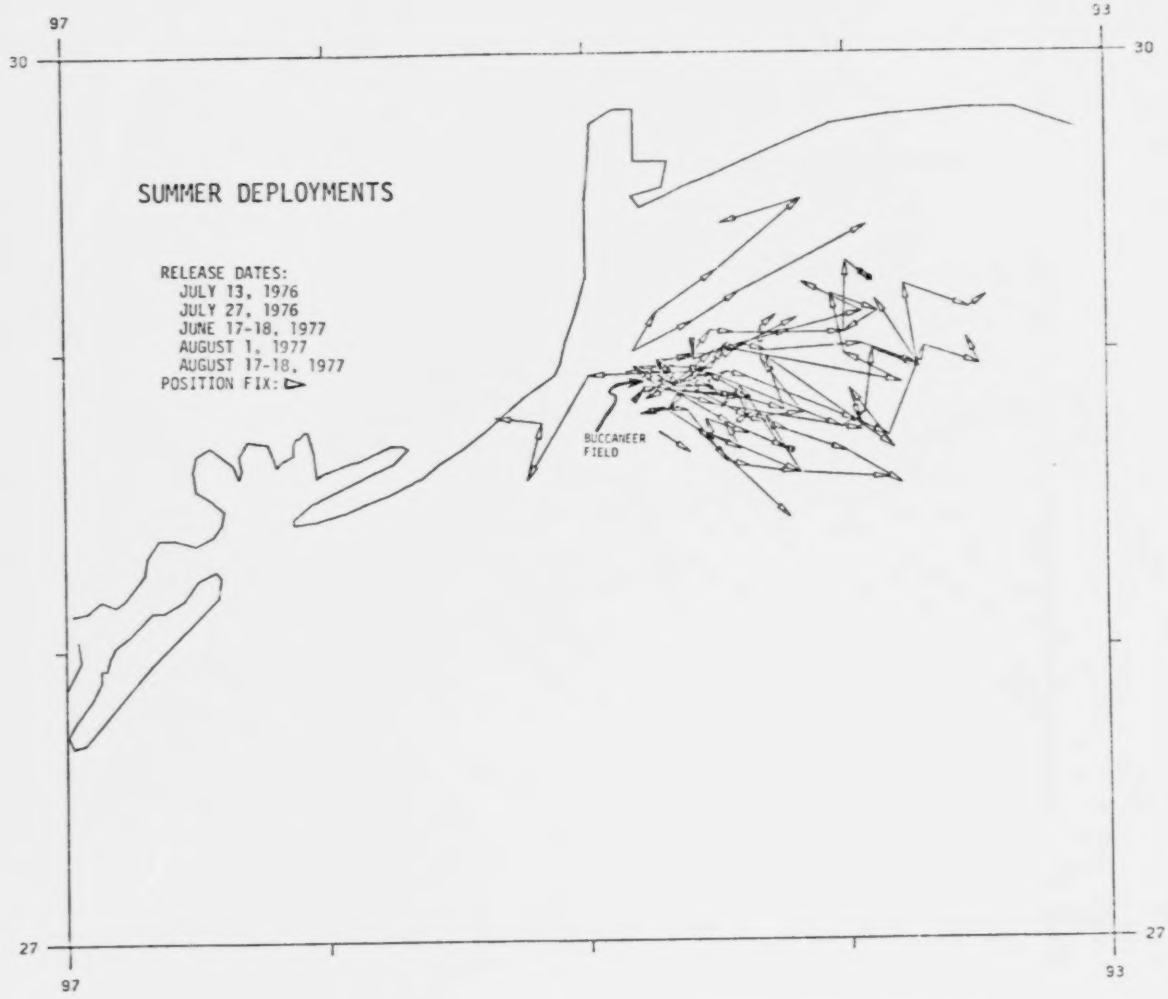

97
93
30
30
SUMMER DEPLOYMENTS
RELEASE DATES:
JULY 13, 1976
JULY 27, 1976
JUNE 17-18, 1977
AUGUST 1, 1977
AUGUST 17-18, 1977
POSITION FIX: ▷
BUCCANEER FIELD
27
27
97
93

Figure 22. Movements of drifting, transponding buoys deployed during summer.

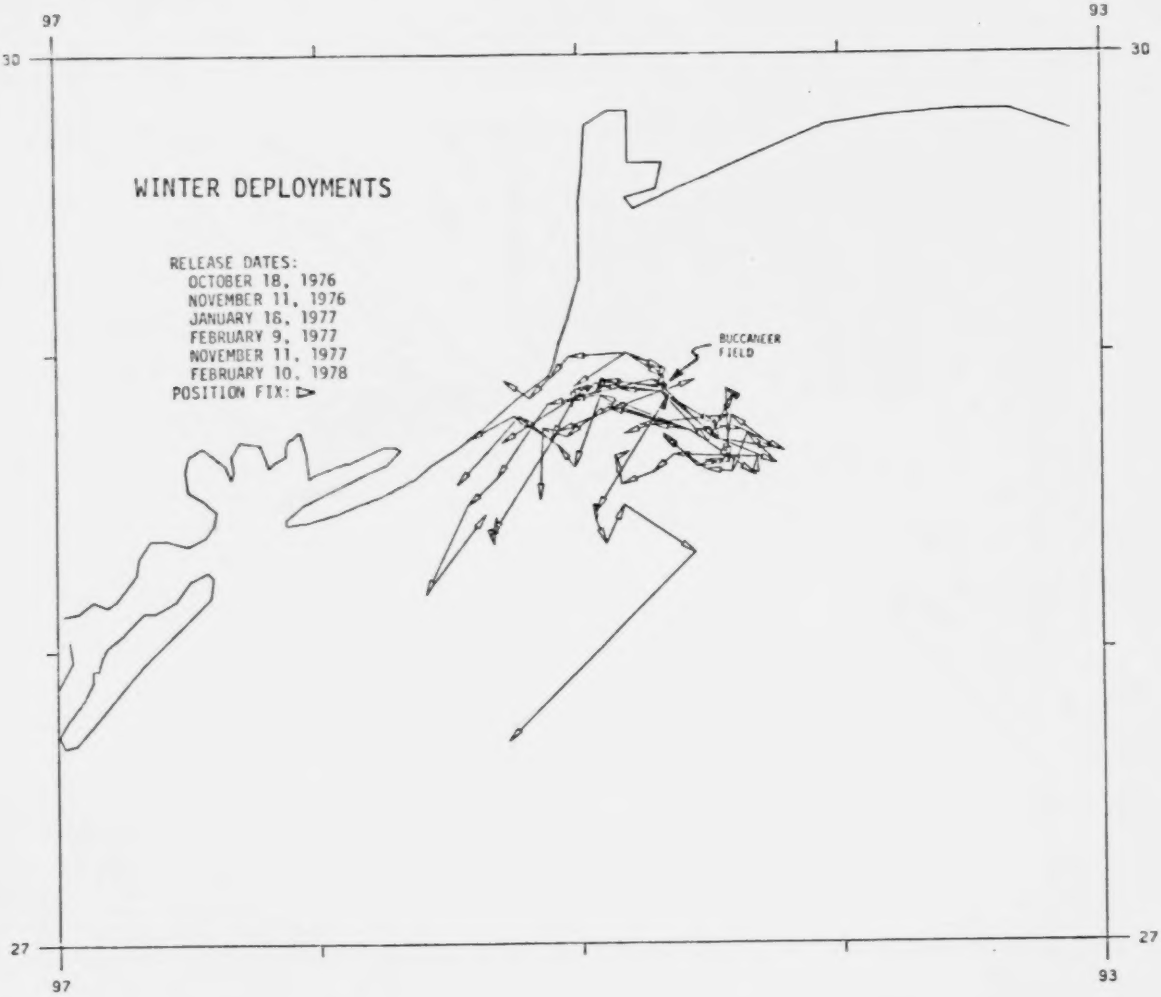

97
93
30
30
WINTER DEPLOYMENTS
RELEASE DATES:
OCTOBER 18, 1976
NOVEMBER 11, 1976
JANUARY 18, 1977
FEBRUARY 9, 1977
NOVEMBER 11, 1977
FEBRUARY 10, 1978
POSITION FIX: ▷
BUCCANEER FIELD
27
27
97
93

Figure 23. Movements of drifting, transponding buoys deployed during winter (including late-fall).

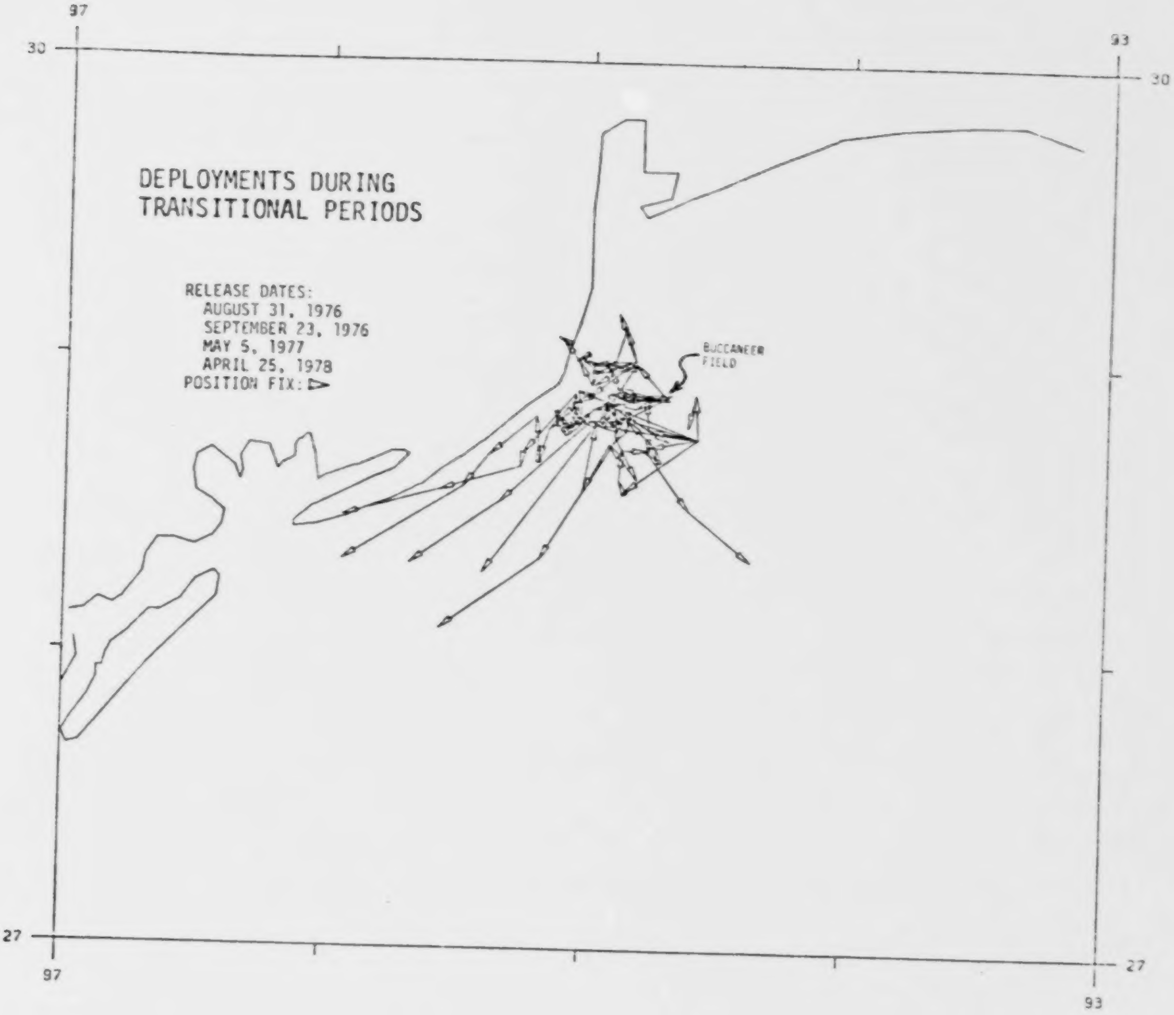

97
30
93
30
DEPLOYMENTS DURING
TRANSITIONAL PERIODS
RELEASE DATES:
AUGUST 31, 1976
SEPTEMBER 23, 1976
MAY 5, 1977
APRIL 25, 1978
POSITION FIX: ▷
BUCCANEER
FIELD
27
97
27
93

Figure 24. Movements of drifting, transponding buoys deployed during transitional periods of early-fall and spring.

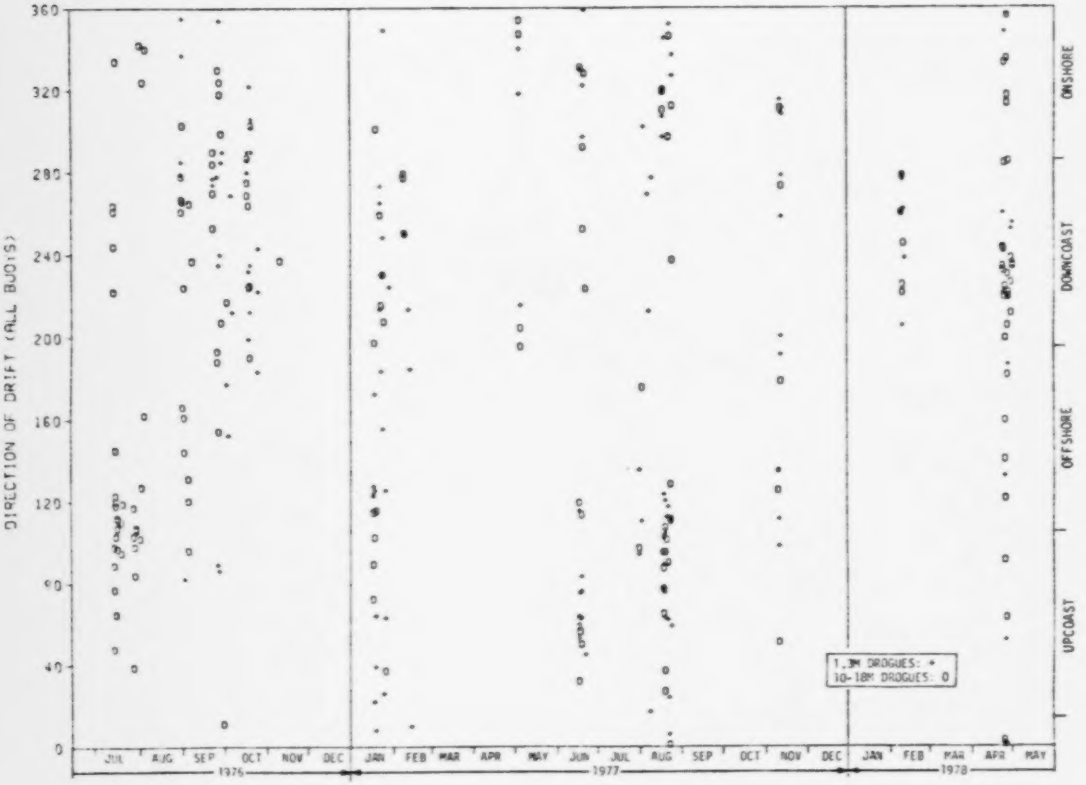


Figure 25. Direction of daily movements of all drifting, transponding buoys deployed and tracked between July 13, 1976 and May 3, 1978.

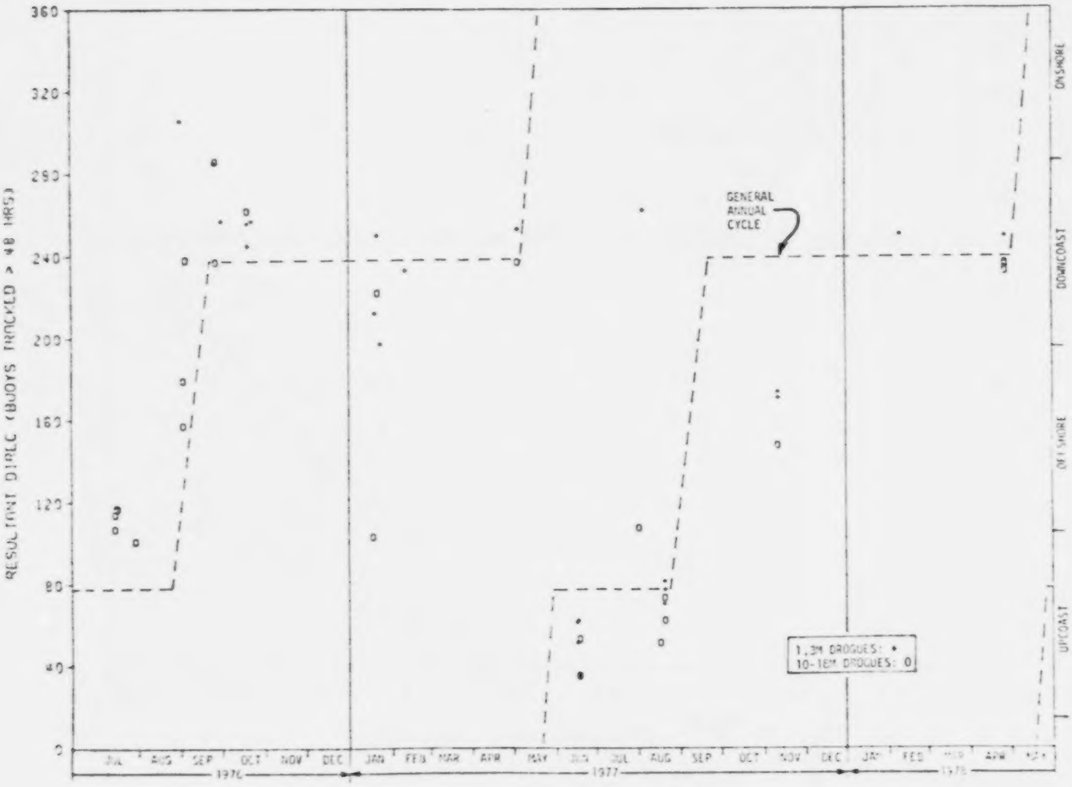


Figure 26. Resultant direction of movement of all drifting transponding buoys tracked for more than 48 hours during July 13, 1976 through May 3, 1978.

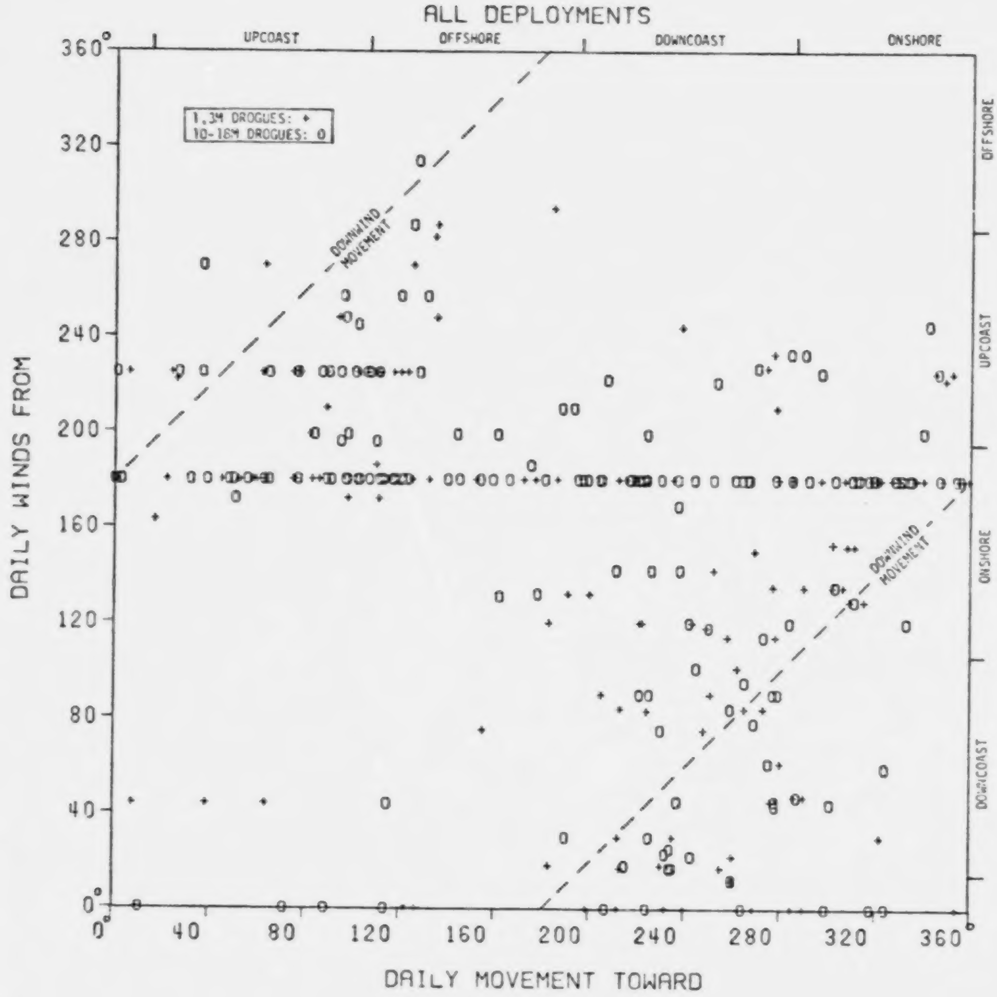


Figure 27. Daily movements of all drifting, transponding buoys versus local prevailing wind direction during buoy movement. (Winds from Galveston Weather Station.)

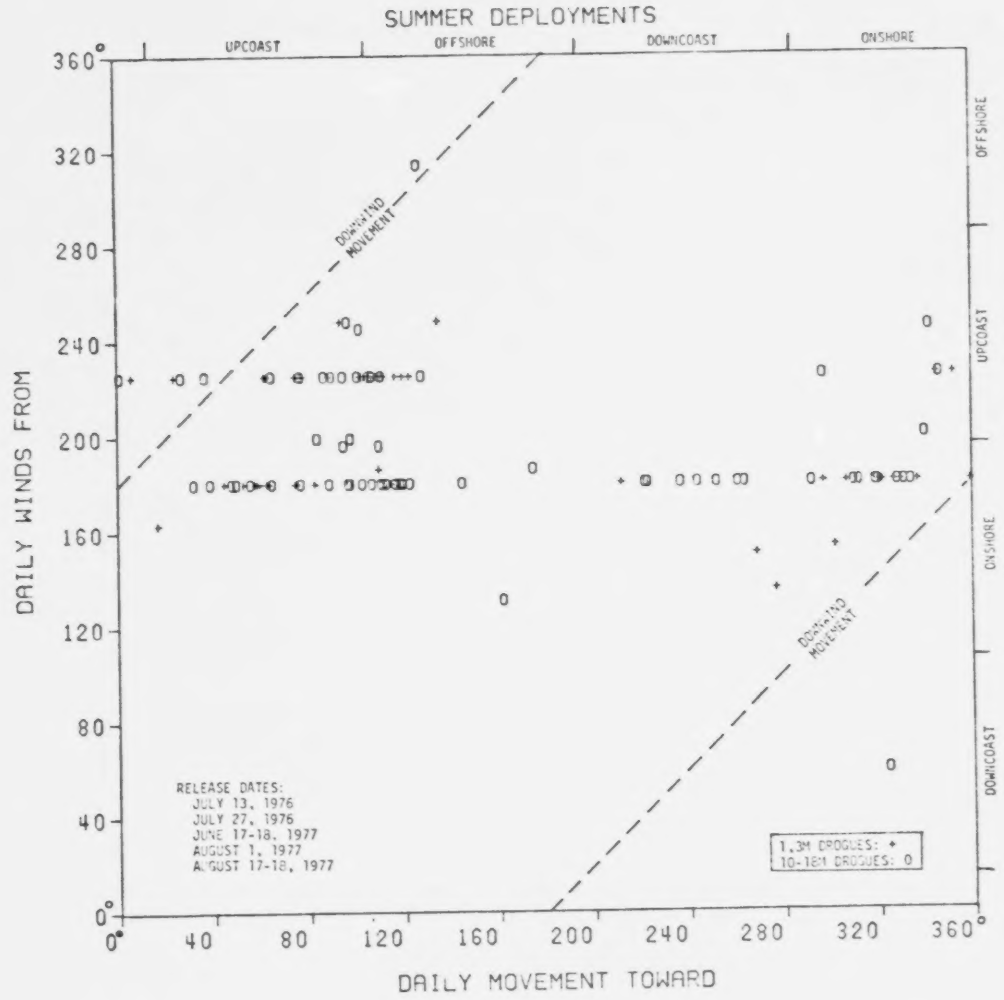


Figure 28. Daily movements of drifting, transponding buoys deployed during summer versus local prevailing wind direction during buoy movement. (Winds from Galveston Weather Station.)

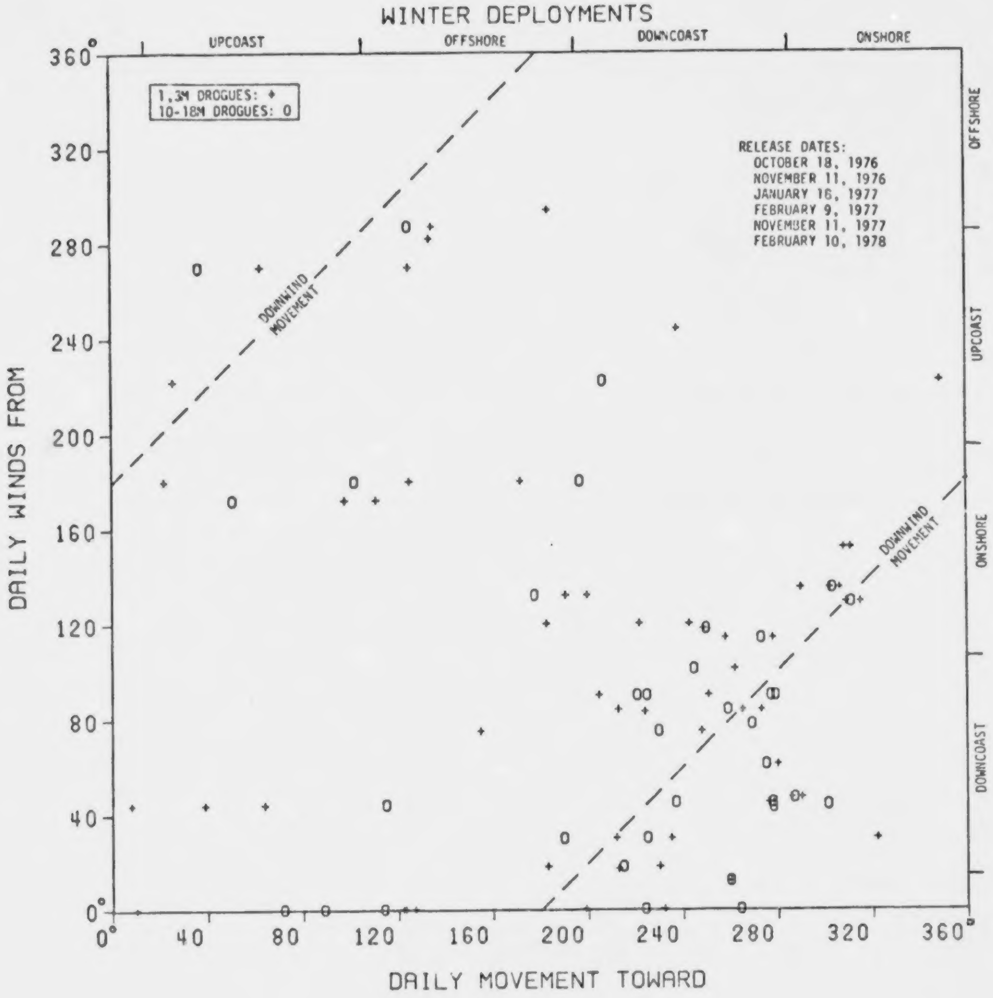


Figure 29. Daily movements of drifting, transponding buoys deployed during winter versus local prevailing wind direction during buoy movement. (Winds from Galveston Weather Station.)

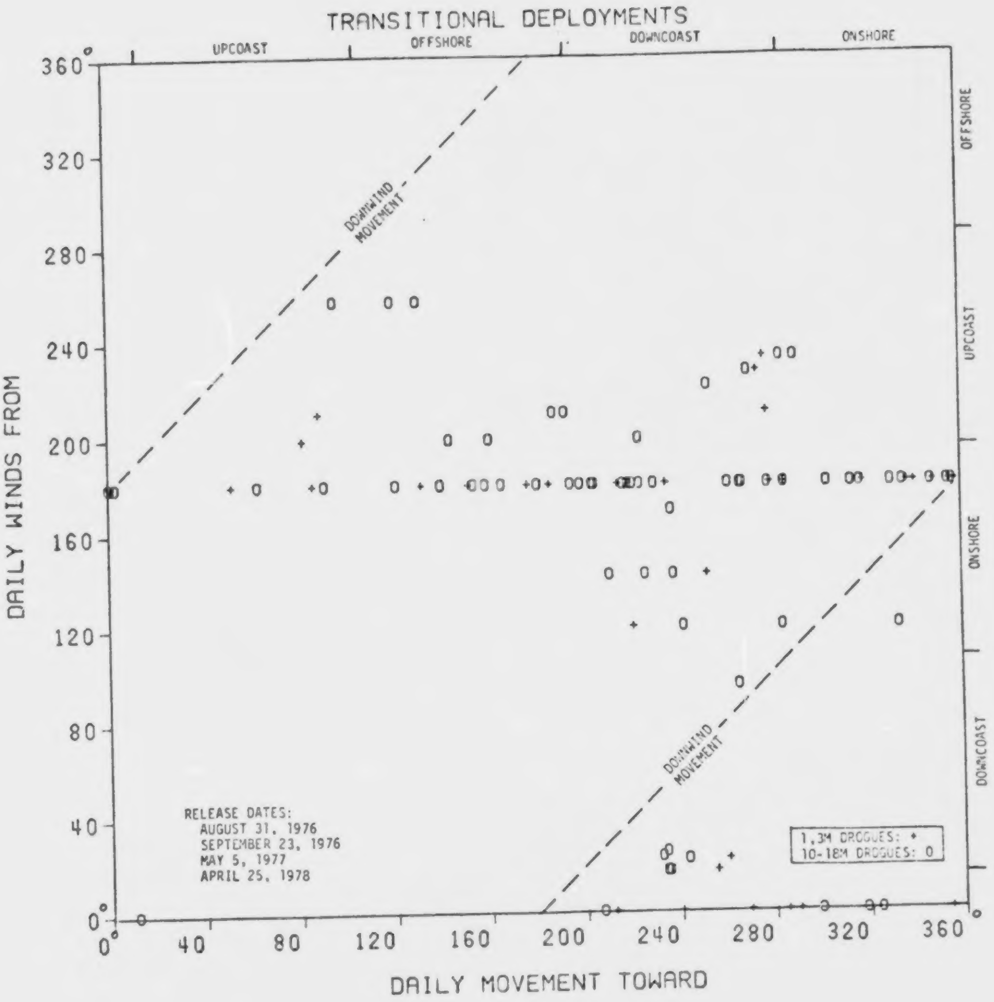


Figure 30. Daily movements of drifting, transponding buoys during transitional periods versus local prevailing wind direction during buoy movement. (Winds from Galveston Weather Station.)

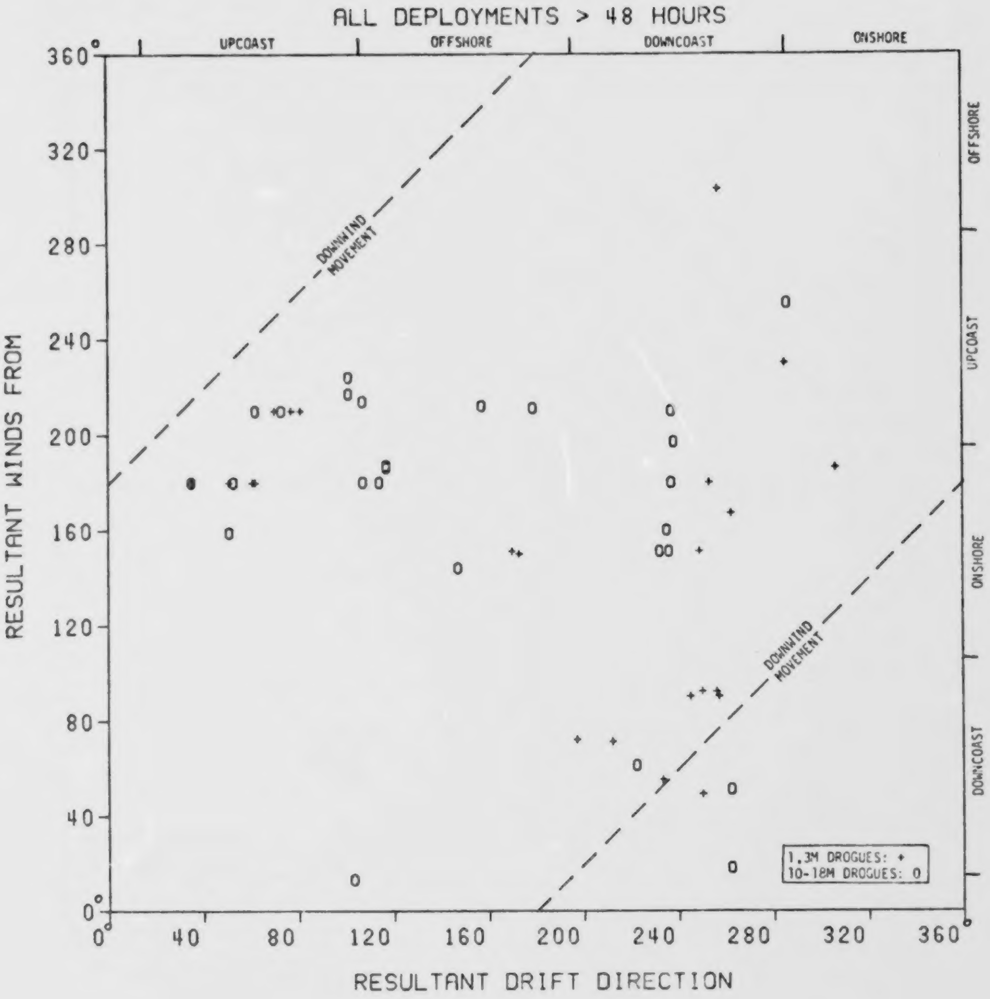


Figure 31. Resultant direction of movement of all drifting, transponding buoys tracked for more than 48 hours versus resultant direction of local winds for period of buoy drift. (Winds from Galveston Weather Station.)

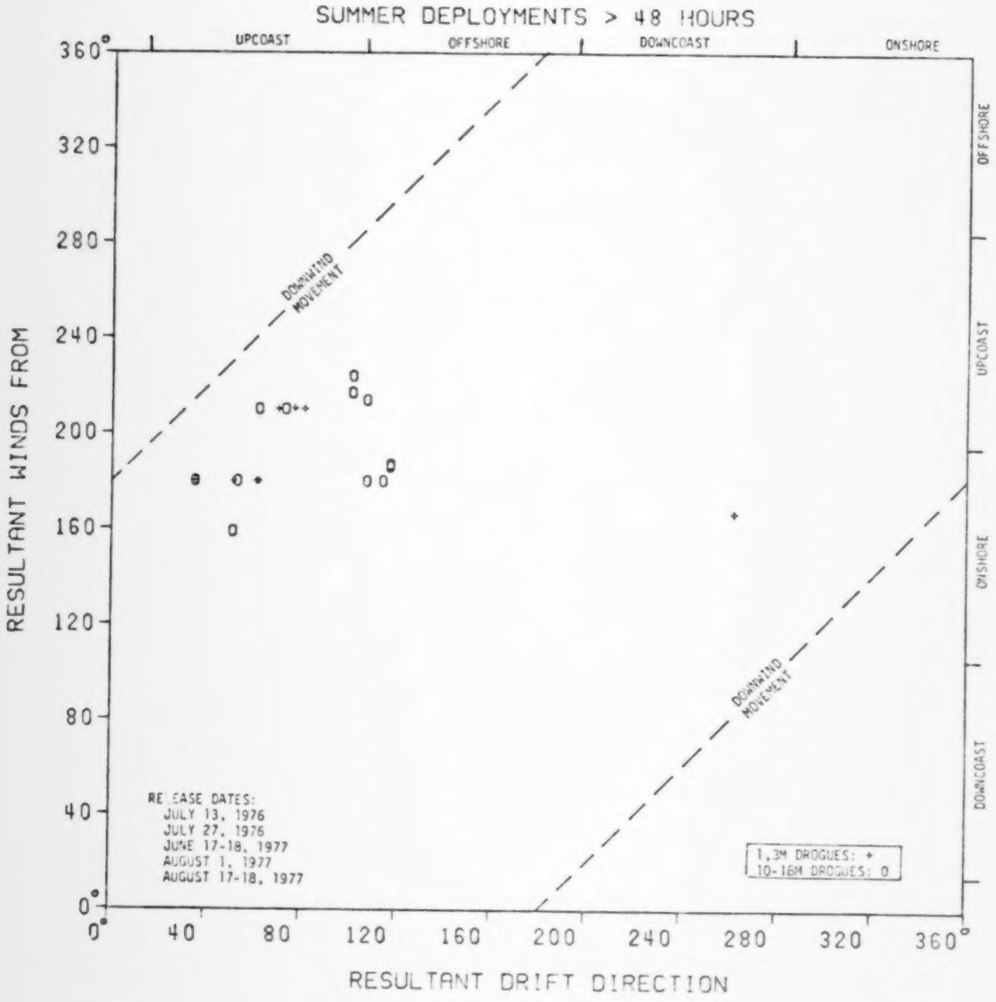


Figure 32. Resultant direction of movement of drifting, transponding buoys deployed during summer and tracked for more than 48 hours versus resultant direction of local winds for period of buoy drift. (Winds from Galveston Weather Station.)

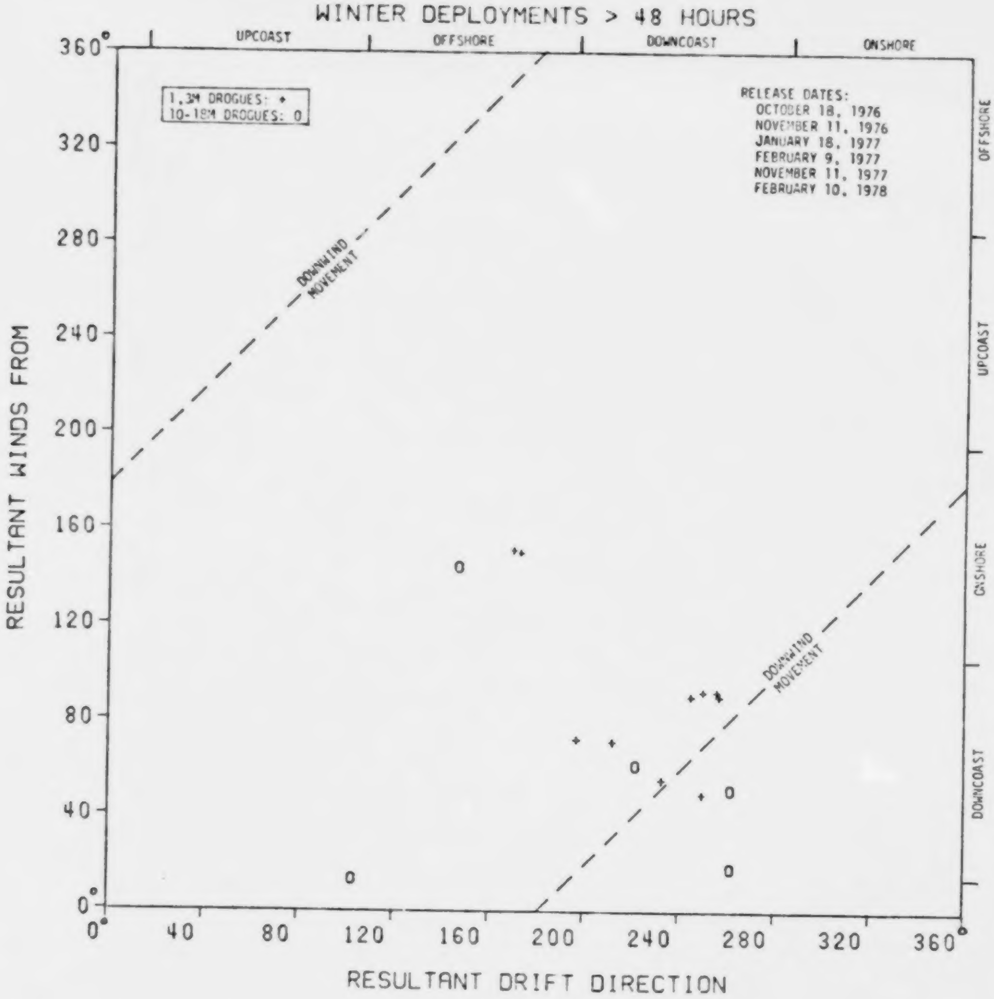


Figure 33. Resultant direction of movement of drifting, transponding buoys deployed during winter and tracked for more than 48 hours versus resultant direction of local winds for period of buoy drift. (Winds from Galveston Weather Station.)

PART B

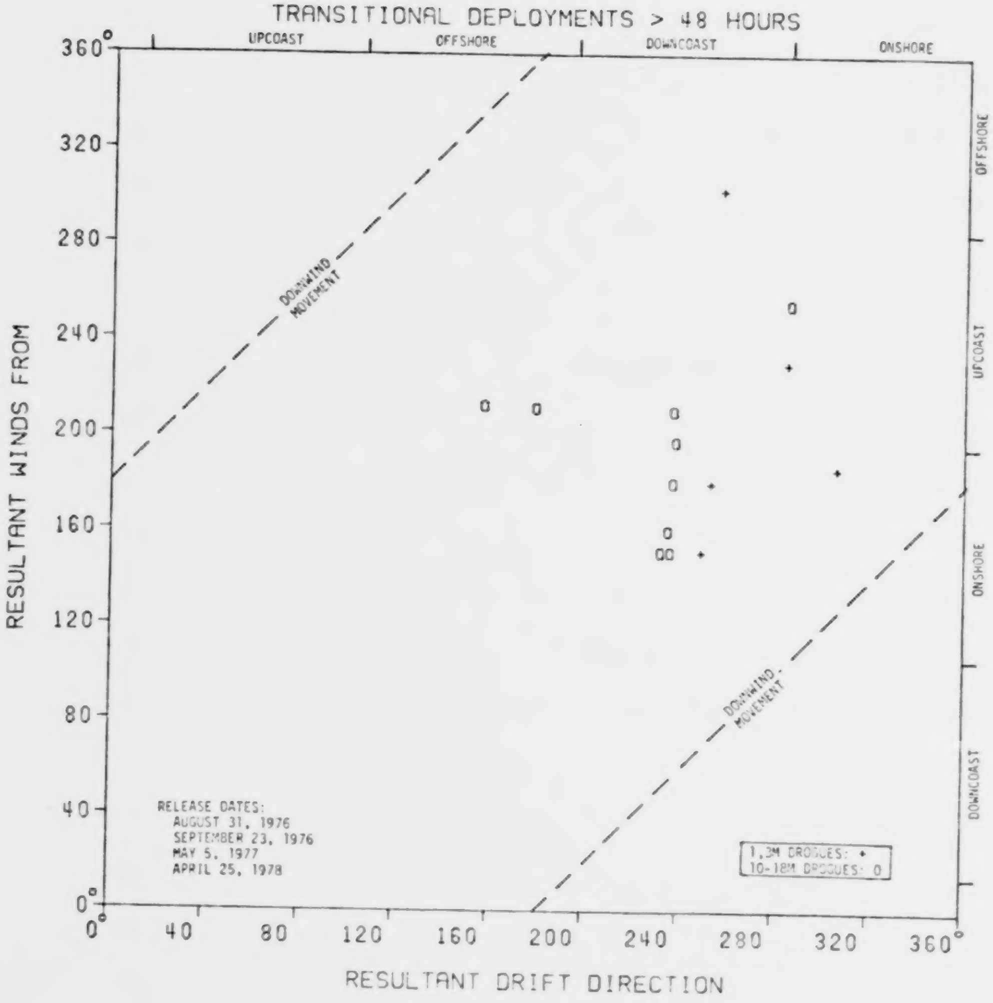


Figure 34. Resultant direction of movement of drifting, transponding buoys during transitional periods and tracked for more than 48 hours versus resultant direction of local winds for period of buoy drift. (Winds from Galveston Weather Station.)

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I. Introduction

The Ocean Current Measuring Program (OCMP) was implemented by Shell Development Company to further increase the knowledge of oceanographic and meteorological parameters as they affect platform design. In particular, information gathered during this program was to be used to increase Shell's knowledge of wave kinematics and hurricane driven currents.

The OCMP consisted of three measurement stations of which Shell's Buccaneer 288-A platform was the first station to be instrumented. This station was originally installed in 1971 as a pilot station to test the operation of the OCMP instrumentation prior to the installation of two additional stations. As the pilot program operated satisfactorily, the other two stations were installed; and the OCMP oficially began collecting data in 1972.

After the program became operational, Shell Development Company solicitated support from other interested companies and was rewarded by the support of Exxon Production Research Company, Amoco Production Company, Mobil Research and Development Company, and Chevron Oil Field Research Company.

The installation and maintenance of the system were conducted by Shell Development Company with the assistance of Evans-Hamilton, Inc.

Station No. 1 of the OCMP was located in Shell's Buccaneer field which was the center of the National Marine Fisheries Service's (NMFS) study area for the Buccaneer Field Studies. As the station was operational during 1976 and was collecting wind and current data during the period of other NMFS field studies, NMFS approached Shell Development Company to obtain the wave and current data for 1976. Permission was obtained from Shell Development Company to obtain the data provided it was obtained from their maintenance contractor, Evans-Hamilton, Inc. (EHI).

NMFS contracted with EHI to obtain the required data and to process and analyze these data into a form which would assist NMFS in the Buccaneer Field Studies.

This report describes the instrumentation on the Buccaneer platform, the quality of the data collected, the methods used to analyze the data, and the results of those data analyses.

II. Buccaneer Instrumentation

The instrumentation system at Buccaneer has been described in detail in two Shell Development Company publications: "Ocean Current Measuring Program: Report on Electronics System", by R. C. Hamilton and "OCMP--Equipment and Station Configurations", by G. Z. Forristall. This report will not go into the detail of those reports but will attempt to cover the significant points of the system so that the reader can have a better understanding of the data collected by the system.

A. General

The overall instrumentation system is shown schematically in Figure 127 while Figure 128 gives a block diagram of the electronic signals. These figures are general for all stations of the system. Buccaneer was different from the other two stations as it only had three current meters instead of four.

Physically Buccaneer platform 288-A consists of two structures connected by a long bridge. The bridge is approximately 19.8m above the water and the two platforms are oriented approximately Northwest-Southwest (324°-144°T). The anemometer is located on a tower near the middle of the bridge putting it 29.9m above mean water level. The current meters were installed at the center of the bridge on a taut wire system which enabled the meters to be retrieved if necessary. The meters were installed at -4.0, -10.0, and -17.7m MGL in water 20.7m deep.

The data were recorded on 7 channel FM analog recorders with the current data on one recorder and the weather data on the other recorder. An accutron time signal was recorded on both recorders to allow proper correlation of the data. Additionally, the clock caused a calibration signal to be put on all data channels simultaneously once every 24 hours.

The entire system was run off D.C. power which was provided by a D.C. power supply when platform power was available and by standby batteries when platform power shut down.

B. Sensors

Wind Speed and direction were measured using a Bendix Model 120 aerovane with a potentiometric direction sensor. The wind speed sensor was a D.C. generator.

Current speed and direction were measured with Marsh-McBirney Model 724 electromagnetic current meters. These meters measure the currents in two horizontal axes, and that data can be combined to provide current speed and direction. These current meters have very rapid response and were selected so that wave particle velocities could be measured; therefore, mean current speed and direction can only be obtained by averaging the data over a given period of time.

Time was provided by an Accutron timer which provided minute and hour pulses on the magnetic tapes. The timer also provided 24 hour pulses which triggered the automatic-calibration circuit which provided two calibration points for each data channel.

C. Recorders

The data were recorded on two Geotech Model 17373 FM analog magnetic tape recorders. These recorders run at 0.03 ips and can record data for up to 33 days continuously. During the OCMP the tapes were changed approximately every 28 days.

D. Automatic-Calibration Circuit

The OCMP stations were provided with a circuit to provide a low and high calibration value for each channel once every 24 hours. For the low calibration value the inputs to the recorders were shorted together to provide a zero input. The high calibration for wind speed and direction were provided by applying substitution voltages to the recorders while the high calibration value for the current meters was provided by the current meter chassis themselves.

III. Data Quality

During the period of interest (ie. 1976) the data when recorded were of good quality. Bad data were easily recognized as the sensors were checked regularly, and the periods when the sensors were defective were easily defined.

Table 24 contains a list by sensor of the periods when useable data were collected. All gaps in the wind data record were caused by tape recorder failures while the gaps in the current meter records were caused by sensor problems and station maintenance.

Small data gaps of a few hours duration which occurred during tape changes and station maintenance have been manually eliminated to make the records continuous where possible.

Accuracy of the data is dependent on the accuracies of the sensor, the recorder, and the digitizing process. It is difficult to determine the absolute accuracy of the data in all cases; however, it is felt in most cases that the accuracy of these data is within plus or minus 5 percent of the indicated value. The absolute accuracy of the current meter data is the most difficult to determine as the scale of the recorders was set at plus and minus 610 cm/sec which is a large span for the magnitude of the mean current speeds actually measured. These scales were selected due to the fact that the system was set up to record wave particle velocities which are of considerably larger magnitude than the mean currents. Additionally, as the currents are so small the zero drift of the sensor and the recorder become very important and are quite often as large or larger than the data. It is therefore felt that any currents with a magnitude of approximately 6 cm/sec or less should be very cautiously utilized as the zero drift of the recorder can be of that magnitude.

The absolute accuracy of the wind speed is dependent on the zero drift of the recorder and the sensor accuracy and is felt to be within ± 1.5m/sec.

Wind direction is felt to be within plus or minus 10 degrees of the recorded reading.

In most instances the data are probably more accurate than the accuracies given above; however, any assumptions made based on greater accuracies should only be made with great caution.

IV. Methods of Analysis

The FM analog tapes for the period December 18, 1975 through December 29, 1976 (26 tapes) were obtained from Shell Development Company. These tapes were played on a Sangamo 3500 tape recorder, and the signals from that recorder were digitized by the 10 bit digitizer of a DEC PDP-11. The tape recorder was run at 30 ips (ie. 1000 times field time), and the data were digitized at 2 kilohertz, (ie. two samples per real time second). The digitizer was triggered off the hour pulses on the tape, and 2048 samples (1024 seconds of data) were obtained from each hour for each channel.

The data were calibrated by separately digitizing a calibration pulse and determining what the calibration values were equal to in digital counts. The calibration values were related to field data from the OCMP station visit logs, and the calibration data were then used to develop linear calibration equations for each data channel. The digitized data were processed by applying the calibration equation to the data for each channel. After the data had been calibrated, they were averaged over the full 1024 second sample period to produce the mean wind speed and direction and the mean current speed and direction for each current meter.

The wind data were broken into components before averaging and then recombined after averaging. As the currents were already in components, they were averaged directly and then combined to give speed and direction.

The wind data were all referenced to True North and gave the average speed and direction toward which the wind was blowing. As the current meter suspension system was twisted, the current meters were not referenced to True North; therefore, the twist corrections for each meter had to be applied before the data were referenced to True North. To reference the current meters to True North, 18 degrees were added to current meter No. 1, 23 degrees to current meter No. 2, and 29 degrees to current meter No. 3.

After the current and wind data were referenced to True North, they all had 60 degrees subtracted from them and were then resolved into Alongshore and Normal-to-Shore components. This rotation of axes produced Alongshore currents and winds which were positive toward the Northeast (060^0) and Normal-to-Shore currents and winds which were positive toward the Southeast (150^0).

Listings were produced of all the processed wind and current data by hour. For the wind the listings contained the time, digital tape number, file number, record number, number of points averaged, wind speed and direction toward which the wind was blowing in degrees relative to True North, the Northerly and Easterly component speeds, the Alongshore and Normal-to-Shore components of the wind. The current listings contained the time, digital tape number, file number, record number, number of points averaged, speed and direction toward which the current was flowing in degrees relative to True North, the Northerly and Easterly current speed relative to True North and the Alongshore and Normal-to-Shore components of the current.

After the initial listings were created, the data were manually "called" to eliminate all periods of bad or suspect data, to correct individual bad data points, and to insert data for short periods of missing data to make the data records continuous where possible. Final listings of the "called" data were then produced, and the data from these listings were used to produce all other data products.

A. Time Histories

Wind speed and direction time histories were produced by month and are given in Figures 1 through 13. The Alongshore and Normal-to-Shore component time histories for Current Meter No. 1 were plotted in Figures 14 through 22, for Current Meter No. 2 in Figures 23 through 33, and for Current Meter No. 3 in Figures 34 through 41.

B. Progressive Vector Diagrams

Progressive vector diagrams for wind (Figures 42 through 54), Current Meter No. 1 (Figures 55 through 63), Current Meter No. 2 (Figures 64 through 74), and Current Meter No. 3 (Figures 75 through 82) were plotted by month. These diagrams were all scaled by sensor so that the month with the largest excursions set the scale for all months. The scales for each current meter were different so that maximum resolutions could be obtained for each meter.

C. Kinetic Energy Density Spectra

For each period of continuous data Kinetic Energy Density versus Frequency plots were produced for wind (Figures 83, 85, 87, 89, 91, 93, and 95), for Current Meter No. 1 (Figures 97 and 99), for Current Meter No. 2 (Figures 101, 103, 105, 107, 109, 111, and 113), and for Current Meter No. 3 (Figures 115, 117, 119, 121, 123, and 125). The Kinetic Energy

Density Spectra were calculated using the Fast Fourier Transform (FFT) algorithm. This algorithm requires that the data set be divisable by two; therefore, the length of record analyzed was always somewhat shorter than the length of record available.

The FFT algorithm produces raw spectral estimates which must be smoothed to produce a useable spectra. The Kinetic Energy Density Spectra were smoothed by the following method: starting at the left side of the plots (ie. lowest frequency) the first 30 points were averaged over one frequency band, the next 15 points were averaged over 2 frequency bands, the next 6 points over 5 frequency bands, the next 30 points over 10 frequency bands, the next 15 points over 20 frequency bands, the next 6 points over 50 frequency bands, the next 30 points over 100 frequency bands, the next 15 points over 200 frequency bands, and the next 6 points over 500 frequency bands if necessary. The Energy Density Spectra were all plotted on log-log graphs.

D. Frequency versus Power Density Spectra

For the same periods for which the Kinetic Energy Density Spectra were produced, Frequency versus Power Density Spectra were calculated for wind and all three current meters. These spectra were produced in essentially the same manner as the Kinetic Energy Density Spectra with the exception that the smoothed Kinetic Energy Density for each frequency band was multiplied times the center frequency of the band over which it was averaged and the resulting product was plotted as the ordinate (ie. Frequency Times Power Density) on a linear scale.

These plots tend to accentuate frequency peaks in the higher frequencies which might otherwise be overlooked. Unfortunately, this representation becomes unuseable for noisy spectra such as those produced from short records.

The Frequency time Power Density Spectra for the wind are given in Figures 84, 86, 88, 90, 92, 94, and 96, for Current Meter No. 1 in Figures 98 and 100, for Current Meter No. 2 in Figures 102, 104, 106, 108, 110, 112, and 114, and for Current Meter No. 3 in Figures 116, 118, 120, 122, 124, and 126.

E. Statistics

Standard statistical parameters were calculated for the wind and the currents at all three depths by month (Tables 1 through 21) and by year (Tables 22 and 23). The parameters calculated are defined as follows: for n speed and direction samples in a time period, we define $A_i = S_i \cos(\Theta_i - 60)$, (ie. alongshore); $N_i = S_i \sin(\Theta_i - 60)$, (ie. normal-to-shore); then for x = A, N, and S.

$$\text{mean} = \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

$$\text{variance} = \sigma_x^{\,2} = \frac{1}{n} \sum_{i=1}^{n} x_i^{\,2} - \bar{x}^2$$

$$\text{standard error of the mean} = \frac{\sigma_x}{\sqrt{n}}$$

$$\text{standard deviation} = \sigma_x$$

$$\text{skewness} = \frac{1}{\sigma_x^{\,3}} \left[\frac{1}{n} \sum_{i=1}^{n} x_i^{\,3} - \frac{3\bar{x}}{n} \sum_{i=1}^{n} x_i^{\,2} + 2\bar{x}^3 \right]$$

$$\text{kurtossis} = \frac{1}{\sigma_x^{\,4}} \left[\frac{1}{n} \sum_{i=1}^{n} x_i^{\,4} - \frac{4\bar{x}}{n} \sum_{i=1}^{n} x_i^{\,3} + \frac{6\bar{x}^2}{n} \sum x_i^{\,2} - 3\bar{x}^4 \right]$$

The "alongshore" and "normal-to-shore" statistics were also calculated as follows:

covariance = $M = \frac{1}{n} \Sigma AN - \overline{AN}$

standard deviation of covariance = $\sigma_m = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (A_i N_i)^2 - \overline{A_i N_i}^2}$

standard error of convariance = $\frac{\sigma_m}{\sqrt{n}}$

correlation coefficient = $M^1 = \frac{M}{\sigma_A \sigma_N}$

Also calculated were parameters related to vector quantities:

Scales amplitude of the vector mean = $V_m = \sqrt{\overline{A}^2 + \overline{N}^2}$

Vector Variance = $V_v{}^2 = 1/2(\sigma_A + \sigma_N{}^2)$

Standard Deviation = V_v

V. Results of Analysis

All wind and current data recorded at Buccaneer between 1200 December 18, 1975 and 1400 December 29, 1976 were analyzed to provide mean wind and current speed and direction for each hour of data. All useable data during that period were analyzed and processed as described in Section IV. The periods for which data were analyzed are listed in Table 24.

The analyzed hourly results were listed by hour, written on digital magnetic and were plotted versus time to provide the time histories of Figures 1 through 41 and the progressive vector diagram of Figure 42 through 82. Additionally, these hourly values were used to determine the Kinetic Energy Density Spectra and the Frequency Times Power Density Spectra (Figures 83 through 126) and to develop the statistics given in Table 1 through 23.

VI. Conclusions

All wind and current data recorded at Shell Oil Company's Buccaneer 288-A platform during the period 1200 December 18, 1975 through 1400 December 29, 1976 were analyzed for the National Marine Fisheries Service. These data were not complete due to sensor and/or recorder failures. A significant amount of data were collected and analyzed; however, and the periods for which data were analyzed are listed in Table 24.

The data analyzed were of good quality with little noise or contamination. The accuracy of the data is considered to be better than 5 percent of the measured value in most cases. The zero drift of the magnetic tape recorder can cause the current data to be off by up to ±6.1 cm/sec and the wind data to be off by up to ±1.5 m/sec. As the zero drift is temperature related and the recorders operated in an air conditioned environment, the data usually have zero drifts lower than those given above. Any conclusions based on greater accuracies than given above should only be drawn with great care.

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7512

WIND STATISTICS -
        (M/SEC)
                     NS         AS       SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
MEAN        =       0.76      -0.88       6.51 * COVARIANCE                 =     1.28
STD. ERR. =         0.34       0.20       0.18 * STD. ERR. OF COVARIANCE =     1.16
VARIANCE  =        38.11      13.39      10.52 * STD. DEV. OF COVARIANCE =    20.78
STD. DEV. =         6.17       3.66       3.24 * CORRELATION COEFFICIENT =     0.06
KURTOSIS  =         2.85       2.29       3.45 * VECTOR MEAN                =     1.17
SKEWNESS  =        -0.03      -0.19       0.87 * VECTOR VARIANCE            =    25.75
                                               * STD. DEV.                  =     5.07

SAMPLE SIZE =  323 POINTS.



 EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

 NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7512

 CURRENT STATISTICS   -10.0m
        (CM/SEC)
                     NS         AS       SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
 MEAN       =       2.87      -1.02      17.50 * COVARIANCE                 =    34.09
 STD. ERR. =        0.44       1.24       0.81 * STD. ERR. OF COVARIANCE =    11.89
 VARIANCE  =       53.80     423.62     180.32 * STD. DEV. OF COVARIANCE =   197.95
 STD. DEV. =        7.33      20.58      13.43 * CORRELATION COEFFICIENT =     0.23
 KURTOSIS  =        3.64       3.22       2.76 * VECTOR MEAN                =     3.05
 SKEWNESS  =       -0.27      -0.09       0.95 * VECTOR VARIANCE            =   238.71
                                               * STD. DEV.                  =    15.45

 SAMPLE SIZE =  277 POINTS.
```

TABLE 1

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7601

WIND STATISTICS -
        (M/SEC)
                    NS        AS      SPEED * *****   NORMAL X ALONGSHORE    *****
                                            *
MEAN        =     -0.27     -0.52     6.60 * COVARIANCE                =    -8.90
STD. ERR. =        0.20      0.20     0.12 * STD. ERR. OF COVARIANCE =     0.85
VARIANCE    =     26.43     26.44     9.65 * STD. DEV. OF COVARIANCE =    22.34
STD. DEV. =        5.14      5.14     3.11 * CORRELATION COEFFICIENT =    -0.34
KURTOSIS    =      3.02      2.35     3.13 * VECTOR MEAN               =     0.59
SKEWNESS    =      0.48     -0.41     0.37 * VECTOR VARIANCE           =    26.43
                                           * STD. DEV.                 =     5.14

SAMPLE SIZE =  685 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7601

CURRENT STATISTICS  -10.0m
        (CM/SEC)
                    NS        AS      SPEED * *****   NORMAL X ALONGSHORE    *****
                                            *
MEAN        =      3.13      7.35    12.49 * COVARIANCE                =     9.74
STD. ERR. =        0.25      0.57     0.38 * STD. ERR. OF COVARIANCE =     4.59
VARIANCE    =     22.90    123.04    53.66 * STD. DEV. OF COVARIANCE =    88.47
STD. DEV. =        4.79     11.09     7.33 * CORRELATION COEFFICIENT =     0.18
KURTOSIS    =      2.70      3.60     3.15 * VECTOR MEAN               =     7.99
SKEWNESS    =     -0.07     -0.47     0.77 * VECTOR VARIANCE           =    72.97
                                           * STD. DEV.                 =     8.54

SAMPLE SIZE =  373 POINTS.
```

TABLE 2

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7602

WIND STATISTICS -
      (M/SEC)
                        NS          AS      SPEED * *****   NORMAL X ALONGSHORE     *****
                                                  *
MEAN        =        -1.60        1.93       6.37 * COVARIANCE                  =     -9.31
STD. ERR. =           0.22        0.14       0.11 * STD. ERR. OF COVARIANCE =          0.67
VARIANCE    =        29.19       11.85       6.74 * STD. DEV. OF COVARIANCE =         16.17
STD. DEV. =           5.40        3.44       2.60 * CORRELATION COEFFICIENT =         -0.50
KURTOSIS    =         3.24        3.66       3.72 * VECTOR MEAN                 =      2.51
SKEWNESS    =         1.06       -0.35       0.45 * VECTOR VARIANCE             =     20.52
                                                  * STD. DEV.                   =      4.53

SAMPLE SIZE =  587 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7602

CURRENT STATISTICS  -10.0m
      (CM/SEC)
                        NS          AS      SPEED * *****   NORMAL X ALONGSHORE     *****
                                                  *
MEAN        =         3.51        1.82      14.32 * COVARIANCE                  =     41.06
STD. ERR. =           0.30        0.60       0.42 * STD. ERR. OF COVARIANCE =          6.88
VARIANCE    =        60.59      250.11     121.22 * STD. DEV. OF COVARIANCE =        181.38
STD. DEV. =           7.78       15.81      11.01 * CORRELATION COEFFICIENT =          0.33
KURTOSIS    =         3.38        3.74       4.00 * VECTOR MEAN                 =      3.95
SKEWNESS    =         0.03        0.44       1.16 * VECTOR VARIANCE             =    155.35
                                                  * STD. DEV.                   =     12.46

SAMPLE SIZE =  696 POINTS.
```

TABLE 3

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7603

WIND STATISTICS -
        (M/SEC)
                    NS          AS       SPEED * *****   NORMAL X ALONGSHORE    *****
                                               *
MEAN       =     -3.23       -0.29       7.32 * COVARIANCE                =    -9.98
STD. ERR.  =      0.18        0.19       0.10 * STD. ERR. OF COVARIANCE  =     0.92
VARIANCE   =     24.13       26.45       7.45 * STD. DEV. OF COVARIANCE  =    25.07
STC. DEV.  =      4.91        5.14       2.73 * CORRELATICN COEFFICIENT  =    -0.39
KURTOSIS   =      3.51        2.92       3.60 * VECTOR MEAN               =     3.24
SKEWNESS   =      1.01       -0.72       0.38 * VECTOR VARIANCE           =    25.29
                                               * STD. DEV.                 =     5.03

SAMPLE SIZE =  744 PCINTS.


CURRENT STATISTICS - SURFACE
       (CM/SEC)
                    NS          AS       SPEED * *****   NORMAL X ALONGSHORE    *****
                                               *
MEAN       =      0.47      -24.38      24.68 * COVARIANCE                =    -5.54
STD. ERR.  =      0.26        0.58       0.58 * STD. ERR. OF COVARIANCE  =     7.21
VARIANCE   =     14.11       67.96      67.67 * STD. DEV. OF COVARIANCE  =   102.51
STC. DEV.  =      3.76        8.24       8.23 * CORRELATICN CCEFFICIENT  =    -0.18
KURTOSIS   =      3.07        3.24       3.25 * VECTOR MEAN               =    24.39
SKEWNESS   =     -0.41       -0.71       0.70 * VECTOR VARIANCE           =    41.04
                                               * STD. DEV.                 =     6.41

SAMPLE SIZE =  202 PCINTS.
```

TABLE 4

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7603

CURRENT STATISTICS  -10.0m
        (CM/SEC)
                     NS         AS      SPEED * *****   NORMAL X ALONGSHORE   *****
                                              *
MEAN        =       0.12     -14.36     17.15 * COVARIANCE                 =      2.23
STD. ERR. =         0.24       0.44      0.36 * STD. ERR. OF COVARIANCE =         5.00
VARIANCE   =       39.95     139.40     91.32 * STD. DEV. OF COVARIANCE =       133.86
STD. DEV. =         6.32      11.81      9.56 * CORRELATION COEFFICIENT =         0.03
KURTOSIS   =        4.00       2.97      2.37 * VECTOR MEAN                =     14.36
SKEWNESS   =       -0.51       0.28      0.35 * VECTOR VARIANCE            =     89.67
                                              * STD. DEV.                  =      9.47

SAMPLE SIZE =  717 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7603

CURRENT STATISTICS  -17.7m
        (CM/SEC)
                     NS         AS      SPEED * *****   NORMAL X ALONGSHORE   *****
                                              *
MEAN        =      -0.12     -11.48     11.81 * COVARIANCE                 =     -4.45
STD. ERR. =         0.27       0.57      0.56 * STD. ERR. OF COVARIANCE =         3.76
VARIANCE   =        7.59      32.98     32.75 * STD. DEV. OF COVARIANCE =        38.16
STD. DEV. =         2.75       5.74      5.72 * CORRELATION COEFFICIENT =        -0.28
KURTOSIS   =        2.83       2.26      2.19 * VECTOR MEAN                =     11.48
SKEWNESS   =        0.21      -0.43      0.39 * VECTOR VARIANCE            =     20.28
                                              * STD. DEV.                  =      4.50

SAMPLE SIZE =  103 POINTS.
```

TABLE 5

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7604

WIND STATISTICS -
       (M/SEC)
                   NS          AS       SPEED * *****   NORMAL X ALONGSHORE   *****
                                              *
MEAN        =    -3.78        2.23       6.03 * COVARIANCE                =    -3.95
STD. ERR. =       0.14        0.12       0.10 * STD. ERR. OF COVARIANCE =       0.76
VARIANCE    =    14.79       10.12       7.77 * STD. DEV. OF COVARIANCE =      20.35
STD. DEV. =       3.85        3.18       2.79 * CORRELATION COEFFICIENT =      -0.32
KURTOSIS    =     3.47        4.01       4.07 * VECTOR MEAN               =     4.39
SKEWNESS    =     0.58        0.09       0.70 * VECTOR VARIANCE           =    12.46
                                              * STD. DEV.                 =     3.53

SAMPLE SIZE =  720 POINTS.




CURRENT STATISTICS - SURFACE
       (CM/SEC)
                   NS          AS       SPEED * *****   NORMAL X ALONGSHORE   *****
                                              *
MEAN        =    -0.39      -21.90      22.36 * COVARIANCE                =   -18.84
STD. ERR. =       0.22        0.58       0.58 * STD. ERR. OF COVARIANCE =       6.88
VARIANCE    =    19.78      134.55     134.29 * STD. DEV. OF COVARIANCE =     138.34
STD. DEV. =       4.45       11.60      11.59 * CORRELATION COEFFICIENT =      -0.37
KURTOSIS    =     3.85        3.95       3.92 * VECTOR MEAN               =    21.91
SKEWNESS    =     0.30       -1.18       1.20 * VECTOR VARIANCE           =    77.17
                                              * STD. DEV.                 =     8.78

SAMPLE SIZE =  404 POINTS.
```

TABLE 6

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7604

CURRENT STATISTICS  -10.0m
      (CM/SEC)
                       NS          AS       SPEED * *****  NORMAL X ALONGSHORE   *****
                                                  *
MEAN       =         0.45      -13.61       15.17 * COVARIANCE                 =    -22.58
STD. ERR. =          0.27        0.65        0.61 * STD. ERR. OF COVARIANCE =          6.94
VARIANCE   =        27.25      163.61      146.09 * STD. DEV. OF COVARIANCE =        136.61
STD. DEV. =          5.22       12.79       12.09 * CORRELATION COEFFICIENT =        -0.34
KURTOSIS   =         3.61        3.91        4.26 * VECTOR MEAN                =     13.62
SKEWNESS   =         0.29       -1.15        1.38 * VECTOR VARIANCE            =     95.43
                                                  * STD. DEV.                  =      9.77

SAMPLE SIZE =  387 POINTS.




EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7604

CURRENT STATISTICS  -17.7m
      (CM/SEC)
                       NS          AS       SPEED * *****  NORMAL X ALONGSHORE   *****
                                                  *
MEAN       =         4.38      -11.60       13.29 * COVARIANCE                 =    -16.20
STD. ERR. =          0.24        0.73        0.70 * STD. ERR. OF COVARIANCE =          7.29
VARIANCE   =        12.56      121.74      111.40 * STD. DEV. OF COVARIANCE =        109.55
STD. DEV. =          3.54       11.03       10.55 * CORRELATION COEFFICIENT =        -0.41
KURTOSIS   =         2.92        3.12        3.35 * VECTOR MEAN                =     12.40
SKEWNESS   =         0.16       -1.07        1.18 * VECTOR VARIANCE            =     67.15
                                                  * STD. DEV.                  =      8.19

SAMPLE SIZE =  226 POINTS.
```

TABLE 7

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7605

WIND STATISTICS -
      (M/SEC)
                      NS         AS      SPEED * *****  NORMAL X ALONGSHORE   *****
                                               *
MEAN       =       -1.05       1.72       5.80 * COVARIANCE                =    -1.53
STD. ERR.  =        0.17       0.17       0.10 * STD. ERR. OF COVARIANCE   =     0.74
VARIANCE   =       17.87      17.88       6.13 * STD. DEV. OF COVARIANCE   =    17.91
STD. DEV.  =        4.23       4.23       2.48 * CORRELATION COEFFICIENT   =    -0.09
KURTOSIS   =        3.12       2.38       5.02 * VECTOR MEAN               =     2.02
SKEWNESS   =       -0.09      -0.17       0.67 * VECTOR VARIANCE           =    17.87
                                               * STD. DEV.                 =     4.23

SAMPLE SIZE =  585 POINTS.
```

TABLE 8

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATICNAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7605

CURRENT STATISTICS   -10.0m
      (CM/SEC)
                      NS         AS      SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
MEAN        =        5.71      10.59     19.82 * COVARIANCE                =    61.74
STD. ERR. =          0.49       0.74      0.56 * STD. ERR. OF COVARIANCE =      12.02
VARIANCE   =       124.90     284.59    161.45 * STD. DEV. OF COVARIANCE =     273.38
STD. DEV. =         11.18      16.87     12.71 * CORRELATION COEFFICIENT =       0.33
KURTOSIS   =         3.71       2.49      2.76 * VECTOR MEAN             =      12.04
SKEWNESS   =         0.96       0.24      0.87 * VECTOR VARIANCE         =     204.74
                                               * STD. DEV.               =      14.31

SAMPLE SIZE =  517 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATICNAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7605

CURRENT STATISTICS   -17.7m
      (CM/SEC)
                      NS         AS      SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
MEAN        =        1.77      13.59     15.88 * COVARIANCE                =    -9.24
STD. ERR. =          0.17       0.56      0.45 * STD. ERR. OF COVARIANCE =       2.97
VARIANCE   =        13.21     140.30     89.35 * STD. DEV. OF COVARIANCE =      62.46
STD. DEV. =          3.63      11.85      9.45 * CORRELATION COEFFICIENT =      -0.21
KURTCSIS   =         3.51       2.02      2.18 * VECTOR MEAN             =      13.71
SKEWNESS   =         0.38      -0.07      0.30 * VECTOR VARIANCE         =      76.76
                                               * STD. DEV.               =       8.76

SAMPLE SIZE =  441 PCINTS.
```

TABLE 9

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7606

WIND STATISTICS -
        (M/SEC)
                         NS          AS      SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN          =       -2.11        2.88       5.10 * COVARIANCE                 =    -0.79
STD. ERR. =            0.11        0.12       0.09 * STD. ERR. OF COVARIANCE =        0.49
VARIANCE   =           9.41        9.53       5.69 * STD. DEV. OF COVARIANCE =       13.12
STD. DEV. =            3.07        3.09       2.39 * CORRELATION COEFFICIENT =       -0.08
KURTOSIS   =           3.99        2.99       2.54 * VECTOR MEAN                =     3.57
SKEWNESS    =          0.59       -0.29      -0.04 * VECTOR VARIANCE            =     9.47
                                                   * STD. DEV.                  =     3.08

SAMPLE SIZE =  720 POINTS.



CURRENT STATISTICS - SURFACE
       (CM/SEC)
                         NS          AS      SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN          =        3.89      -14.85      19.26 * COVARIANCE                 =    50.42
STD. ERR. =            0.41        0.53       0.42 * STD. ERR. OF COVARIANCE =        8.39
VARIANCE   =          81.08      140.31      86.30 * STD. DEV. OF COVARIANCE =      186.31
STC. DEV. =            9.00       11.85       9.29 * CORRELATION COEFFICIENT =        0.47
KURTOSIS   =           4.51        3.28       2.09 * VECTOR MEAN                =    15.35
SKEWNESS    =          0.60        0.48       0.32 * VECTOR VARIANCE            =   110.70
                                                   * STD. DEV.                  =    10.52

SAMPLE SIZE =  493 PCINTS.
```

TABLE 10

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7606

CURRENT STATISTICS  -10.0m

        (CM/SEC)     NS          AS        SPEED * *****   NORMAL X ALONGSHORE    *****
                                                 *
MEAN         =       3.13       -1.66      15.90 * COVARIANCE                 =     65.71
STD. ERR. =          0.44        0.60       0.45 * STD. ERR. OF COVARIANCE =        42.39
VARIANCE   =       134.70      250.39     144.88 * STD. DEV. OF COVARIANCE =      1126.36
STD. DEV. =         11.61       15.62      12.04 * CORRELATION COEFFICIENT =         0.36
KURTOSIS   =       117.01       13.91     192.07 * VECTOR MEAN                =      3.54
SKEWNESS   =        -6.86       -1.04      10.19 * VECTOR VARIANCE            =    192.55
                                                 * STD. DEV.                  =     13.88

SAMPLE SIZE =  706 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7606

CURRENT STATISTICS  -17.7m
        (CM/SEC)
                     NS          AS        SPEED * *****   NORMAL X ALONGSHORE    *****
                                                 *
MEAN         =       3.13        8.50      11.55 * COVARIANCE                 =     16.13
STD. ERR. =          0.19        0.37       0.31 * STD. ERR. OF COVARIANCE =         3.45
VARIANCE   =        25.09       95.93      69.47 * STD. DEV. OF COVARIANCE =        91.78
STD. DEV. =          5.01        9.79       8.34 * CORRELATION COEFFICIENT =         0.33
KURTOSIS   =         4.55        2.37       2.83 * VECTOR MEAN                =      9.05
SKEWNESS   =         0.49        0.53       0.90 * VECTOR VARIANCE            =     60.51
                                                 * STD. DEV.                  =      7.78

SAMPLE SIZE =  706 POINTS.
```

TABLE 11

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7607

WIND STATISTICS -
      (M/SEC)
                     NS          AS      SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
MEAN        =     -0.36        3.79       4.47 * COVARIANCE                =    -0.36
STD. ERR.   =      0.08        0.11       0.10 * STD. ERR. OF COVARIANCE   =     0.37
VARIANCE    =      3.89        7.07       5.53 * STD. DEV. OF COVARIANCE   =     9.08
STD. DEV.   =      1.97        2.66       2.35 * CORRELATION COEFFICIENT   =    -0.07
KURTOSIS    =      3.07        3.35       2.75 * VECTOR MEAN               =     3.81
SKEWNESS    =     -0.07       -0.02       0.24 * VECTOR VARIANCE           =     5.48
                                               * STD. DEV.                 =     2.34

SAMPLE SIZE =  588 POINTS.



CURRENT STATISTICS - SURFACE
      (CM/SEC)
                     NS          AS      SPEED * *****  NORMAL X ALONGSHORE    *****
                                               *
MEAN        =      1.10       -0.92       8.50 * COVARIANCE                =    15.94
STD. ERR.   =      0.24        0.26       0.18 * STD. ERR. OF COVARIANCE   =     2.01
VARIANCE    =     44.54       48.89      23.19 * STD. DEV. OF COVARIANCE   =    54.78
STD. DEV.   =      6.67        6.99       4.82 * CORRELATION COEFFICIENT   =     0.34
KURTOSIS    =      3.00        4.00       4.77 * VECTOR MEAN               =     1.43
SKEWNESS    =      0.23        0.54       1.13 * VECTOR VARIANCE           =    46.71
                                               * STD. DEV.                 =     6.83

SAMPLE SIZE =  744 POINTS.
```

TABLE 12

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7607

CURRENT STATISTICS  -10.0m
     (CM/SEC)
                   NS        AS     SPEED * *****  NORMAL X ALONGSHORE  *****
                                          *
MEAN       =      3.31      7.31    11.76 * COVARIANCE                =   20.62
STD. ERR.  =      0.30      0.32     0.30 * STD. ERR. OF COVARIANCE   =    4.60
VARIANCE   =     66.30     74.89    67.22 * STD. DEV. OF COVARIANCE   =  125.37
STD. DEV.  =      8.14      8.65     8.20 * CORRELATION COEFFICIENT   =    0.29
KURTOSIS   =      4.29      4.38     4.98 * VECTOR MEAN               =    8.02
SKEWNESS   =      0.81      0.77     1.28 * VECTOR VARIANCE           =   70.60
                                          * STD. DEV.                 =    8.40

SAMPLE SIZE =  744 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7607

CURRENT STATISTICS  -17.7m
     (CM/SEC)
                   NS        AS     SPEED * *****  NORMAL X ALONGSHORE  *****
                                          *
MEAN       =      2.74      4.41     7.61 * COVARIANCE                =    2.55
STD. ERR.  =      0.14      0.22     0.16 * STD. ERR. OF COVARIANCE   =    1.34
VARIANCE   =     13.87     36.24    19.17 * STD. DEV. OF COVARIANCE   =   36.60
STD. DEV.  =      3.72      6.02     4.38 * CORRELATION COEFFICIENT   =    0.11
KURTOSIS   =      3.44      2.55     2.71 * VECTOR MEAN               =    5.19
SKEWNESS   =      0.32      0.01     0.63 * VECTOR VARIANCE           =   25.06
                                          * STD. DEV.                 =    5.01

SAMPLE SIZE =  744 POINTS.
```

TABLE 13

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7608

WIND STATISTICS -
     (M/SEC)
                   NS         AS      SPEED * *****   NORMAL X ALONGSHORE    *****
                                            *
MEAN        =    -1.60       1.88      4.06 * COVARIANCE                =    -0.45
STD. ERR.   =     0.13       0.08      0.09 * STD. ERR. OF COVARIANCE   =     0.40
VARIANCE    =    11.03       4.57      5.21 * STD. DEV. OF COVARIANCE   =    10.50
STD. DEV.   =     3.32       2.14      2.28 * CORRELATION COEFFICIENT   =    -0.06
KURTOSIS    =     3.28       4.06      4.16 * VECTOR MEAN               =     2.47
SKEWNESS    =    -0.20      -0.46      0.65 * VECTOR VARIANCE           =     7.80
                                            * STD. DEV.                 =     2.79

SAMPLE SIZE =  693 POINTS.



CURRENT STATISTICS - SURFACE
     (CM/SEC)
                   NS         AS      SPEED * *****   NORMAL X ALONGSHORE    *****
                                            *
MEAN        =     0.78      -6.70     14.25 * COVARIANCE                =    55.67
STD. ERR.   =     0.27       0.49      0.32 * STD. ERR. OF COVARIANCE   =     4.69
VARIANCE    =    54.54     179.80     76.96 * STD. DEV. OF COVARIANCE   =   127.83
STD. DEV.   =     7.39      13.41      8.77 * CORRELATION COEFFICIENT   =     0.56
KURTOSIS    =     3.99       3.48      2.75 * VECTOR MEAN               =     6.75
SKEWNESS    =     0.33       0.59      0.63 * VECTOR VARIANCE           =   117.17
                                            * STD. DEV.                 =    10.82

SAMPLE SIZE =  744 POINTS.
```

TABLE 14

```
EVANS-HAMILTON CCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHcRIES BUCCANEER DATA ANALYSIS - DATE - 7608

CURRENT STATISTICS  -10.0m
       (CM/SEC)
                          NS          AS       SPEED * *****  NORMAL X ALONGSHORE   *****
                                                     *
MEAN         =          8.68       21.65       26.48 * COVARIANCE                =    87.76
STD. ERR. =             2.67        2.19        2.42 * STD. ERR. OF COVARIANCE =      69.30
VARIANCE  =           184.80      124.96      152.76 * STD. DEV. OF COVARIANCE =     353.38
STD. DEV. =            13.59       11.18       12.36 * CORRELATION COEFFICIENT =       0.58
KURTOSIS  =             1.57        1.75        1.33 * VECTOF MEAN               =    23.32
SKEWNESS  =            -0.08        0.45        0.13 * VECTOR VARIANCE           =   154.88
                                                     * STD. DEV.                 =    12.44

SAMPLE SIZE =   26 PCINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7608

CURRENT STATISTICS  -17.7m
       (CM/SEC)
                          NS          AS       SPEED * *****  NORMAL X ALONGSHORE   *****
                                                     *
MEAN         =          0.04        0.03        7.40 * COVARIANCE                =    -4.06
STD. ERR. =             0.17        0.37        0.22 * STD. ERR. OF COVARIANCE =       1.85
VARIANCE  =            13.76       65.09       24.03 * STD. DEV. CF COVARIANCE =      40.76
STD. DEV. =             3.71        8.07        4.90 * CORRELATION COEFFICIENT =      -0.14
KURTOSIS  =             2.76        3.99        8.34 * VECTOR MEAN               =     0.35
SKEWNESS  =             0.29        0.41        1.45 * VECTOR VARIANCE           =    39.42
                                                     * STD. DEV.                 =     6.28

SAMPLE SIZE =  484 PCINTS.
```

TABLE 15

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7609

WIND STATISTICS -
        (M/SEC)
                     NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                *
MEAN        =     -1.25        0.79        4.72 * COVARIANCE                 =    -3.05
STD. ERR. =        0.13        0.14        0.08 * STD. ERR. OF COVARIANCE =        0.48
VARIANCE  =       11.54       13.32        4.75 * STD. DEV. OF COVARIANCE =       12.97
STD. DEV. =        3.40        3.65        2.18 * CORRELATION COEFFICIENT =       -0.25
KURTCSIS  =        2.54        2.68        2.82 * VECTOR MEAN                =     1.48
SKEWNESS  =        0.33       -0.39        0.12 * VECTOR VARIANCE            =    12.43
                                                * STD. DEV.                  =     3.53

SAMPLE SIZE =  720 POINTS.




CURRENT STATISTICS - SURFACE
        (CM/SEC)
                     NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                *
MEAN        =    -10.86       -4.19       15.44 * COVARIANCE                 =    -2.22
STD. ERR. =        0.27        0.35        0.23 * STD. ERR. OF COVARIANCE =        4.90
VARIANCE  =       53.21       87.01       37.29 * STD. DEV. OF COVARIANCE =      131.43
STD. DEV. =        7.29        9.33        6.11 * CORRELATION COEFFICIENT =       -0.03
KURTOSIS  =        3.85        2.53        2.82 * VECTOR MEAN                =    11.64
SKEWNESS  =        0.80       -0.01        0.14 * VECTOR VARIANCE            =    70.11
                                                * STD. DEV.                  =     8.37

SAMPLE SIZE =  720 POINTS.
```

TABLE 16

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7609

CURRENT STATISTICS   -10.0m
        (CM/SEC)
                      NS          AS        SPEED * *****   NORMAL X ALONGSHORE    *****
                                                  *
MEAN        =      -1.20      -13.90        15.49 * COVARIANCE                =     10.09
STD. ERR. =         0.22        0.42         0.38 * STD. ERR. OF COVARIANCE =       3.98
VARIANCE  =        25.66       96.21        76.61 * STD. DEV. OF COVARIANCE =      92.38
STD. DEV. =         5.07        9.81         6.75 * CORRELATION COEFFICIENT =       0.20
KURTOSIS  =         3.09        2.39         2.22 * VECTOR MEAN               =     13.96
SKEWNESS  =        -0.33       -0.06         0.34 * VECTOR VARIANCE           =     60.94
                                                  * STD. DEV.                 =      7.81

SAMPLE SIZE =  540 POINTS.
```

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7609

CURRENT STATISTICS   -17.7m
        (CM/SEC)
                      NS          AS        SPEED * *****   NORMAL X ALONGSHORE    *****
                                                  *
MEAN        =      -0.68       -3.39         8.28 * COVARIANCE                =      5.20
STD. ERR. =         0.15        0.30         0.19 * STD. ERR. OF COVARIANCE =       1.47
VARIANCE  =        16.81       65.97        26.23 * STD. DEV. OF COVARIANCE =      39.36
STD. DEV. =         4.10        8.12         5.12 * CORRELATION COEFFICIENT =       0.16
KURTOSIS  =         2.85        2.58         2.81 * VECTOR MEAN               =      3.46
SKEWNESS  =        -0.12       -0.09         0.73 * VECTOR VARIANCE           =     41.39
                                                  * STD. DEV.                 =      6.43

SAMPLE SIZE =  720 POINTS.
```

TABLE 17

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7610

WIND STATISTICS -
        (M/SEC)
                         NS          AS       SPEED * *****  NORMAL X ALONGSHORE     *****
                                                    *
MEAN        =         -0.82        0.36        6.06 * COVARIANCE                  =     -6.17
STD. ERR. =           0.21        0.15        0.12 * STD. ERR. OF COVARIANCE =      0.80
VARIANCE  =          31.47       15.97       11.55 * STD. DEV. OF COVARIANCE =     21.95
STD. DEV. =           5.61        4.00        3.40 * CORRELATION COEFFICIENT =     -0.28
KURTOSIS  =           3.10        3.06        3.77 * VECTOR MEAN                 =      0.89
SKEWNESS  =          -0.25        0.35        0.86 * VECTOR VARIANCE             =     23.72
                                                    * STD. DEV.                   =      4.87

SAMPLE SIZE =  744 POINTS.


CURRENT STATISTICS - SURFACE
       (CM/SEC)
                         NS          AS       SPEED * *****  NORMAL X ALONGSHORE     *****
                                                    *
MEAN        =         -3.85      -27.75       29.66 * COVARIANCE                  =    -42.63
STD. ERR. =           0.25        0.63        0.57 * STD. ERR. OF COVARIANCE =      6.24
VARIANCE  =          45.71      293.65      244.45 * STD. DEV. OF COVARIANCE =    170.19
STD. DEV. =           6.76       17.14       15.63 * CORRELATION COEFFICIENT =     -0.37
KURTOSIS  =           3.33        2.77        2.82 * VECTOR MEAN                 =     28.02
SKEWNESS  =          -0.03       -0.62        0.83 * VECTOR VARIANCE             =    169.68
                                                    * STD. DEV.                   =     13.03

SAMPLE SIZE =  744 POINTS.
```

TABLE 18

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7610

CURRENT STATISTICS   -10.0m
     (CM/SEC)
                      NS        AS     SPEED * *****   NORMAL X ALONGSHORE    *****
                                             *
MEAN        =      -2.81    -16.22     17.48 * COVARIANCE                =    -9.25
STD. ERR. =         0.36      0.37      0.36 * STD. ERR. OF COVARIANCE =      6.25
VARIANCE    =      32.56     34.65     32.72 * STD. DEV. OF COVARIANCE =     98.19
STD. DEV. =         5.71      5.89      5.72 * CORRELATION COEFFICIENT =     -0.28
KURTOSIS    =       2.86      2.86      2.90 * VECTOR MEAN               =    16.46
SKEWNESS    =      -0.37     -0.82      0.70 * VECTOR VARIANCE           =    33.60
                                             * STD. DEV.                 =     5.80

SAMPLE SIZE =  247 PCINTS.
```

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7610

CURRENT STATISTICS   -17.7m
     (CM/SEC)
                      NS        AS     SPEED * *****   NORMAL X ALONGSHORE    *****
                                             *
MEAN        =      -3.81    -19.69     21.11 * COVARIANCE                =    28.51
STD. ERR. =         0.18      0.59      0.57 * STD. ERR. OF COVARIANCE =      6.32
VARIANCE    =      23.12    241.99    221.80 * STD. DEV. OF COVARIANCE =    166.43
STD. DEV. =         4.81     15.56     14.89 * CORRELATION COEFFICIENT =      0.38
KURTOSIS    =       2.59      3.20      3.07 * VECTOR MEAN               =    20.05
SKEWNESS    =      -0.10     -0.71      0.89 * VECTOR VARIANCE           =   132.56
                                             * STD. DEV.                 =    11.51

SAMPLE SIZE =  693 PCINTS.
```

TABLE 19

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7611

WIND STATISTICS -
          (M/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN        =        -1.45       -0.20        5.42 * COVARIANCE                 =      -2.49
STD. ERR. =           0.22        0.20        0.15 * STD. ERR. OF COVARIANCE =          0.84
VARIANCE    =        19.54       16.98        9.28 * STD. DEV. OF COVARIANCE =         16.98
STD. DEV. =           4.42        4.12        3.05 * CORRELATION COEFFICIENT =         -0.14
KURTOSIS    =         3.48        3.33        3.88 * VECTOR MEAN                =       1.46
SKEWNESS    =        -0.83       -0.38        1.20 * VECTOR VARIANCE            =      18.26
                                                   * STD. DEV.                  =       4.27

SAMPLE SIZE =  410 PCINTS.




CURRENT STATISTICS - SURFACE
         (CM/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN        =         2.97      -26.28       28.32 * COVARIANCE                 =    -130.36
STD. ERR. =           0.44        0.86        0.89 * STD. ERR. OF COVARIANCE =         47.79
VARIANCE    =       141.35      532.06      570.85 * STD. DEV. OF COVARIANCE =       1282.21
STD. DEV. =          11.89       23.07       23.89 * CORRELATION COEFFICIENT =         -0.48
KURTOSIS    =        24.02        8.24       12.53 * VECTOR MEAN                =      26.44
SKEWNESS    =         3.63       -1.55        2.25 * VECTOR VARIANCE            =     336.70
                                                   * STD. DEV.                  =      18.35

SAMPLE SIZE =  720 PCINTS.
```

TABLE 20

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE - 7612

WIND STATISTICS -
        (M/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN         =        0.30        2.34        7.93 * COVARIANCE                =    -15.45
STD. ERR. =           0.24        0.20        0.11 * STD. ERR. OF COVARIANCE =        1.07
VARIANCE     =       39.09       27.16        8.87 * STD. DEV. OF COVARIANCE =       27.96
STD. DEV. =           6.25        5.21        2.98 * CORRELATION COEFFICIENT =       -0.47
KURTOSIS     =        1.79        2.37        2.47 * VECTOR MEAN               =      2.36
SKEWNESS     =        0.02       -0.05       -0.16 * VECTOR VARIANCE           =     33.13
                                                   * STD. DEV.                 =      5.76

SAMPLE SIZE =  682 POINTS.


CURRENT STATISTICS - SURFACE
        (CM/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE     *****
                                                   *
MEAN         =        1.06        5.53       11.07 * COVARIANCE                =     14.42
STD. ERR. =           0.14        0.44        0.28 * STD. ERR. OF COVARIANCE =        2.66
VARIANCE     =       13.26      131.93       54.27 * STD. DEV. OF COVARIANCE =       69.58
STD. DEV. =           3.64       11.49        7.37 * CORRELATION COEFFICIENT =        0.34
KURTOSIS     =        7.72        2.68        4.70 * VECTOR MEAN               =      5.63
SKEWNESS     =        0.92        0.19        1.21 * VECTOR VARIANCE           =     72.60
                                                   * STD. DEV.                 =      8.52

SAMPLE SIZE =  682 POINTS.
```

TABLE 21

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATIONAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE -   76

ANNUAL WIND STATISTICS (AVERAGED) -
        (M/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE    *****
                                                   *
MEAN         =       -1.39        1.32        5.88 * COVARIANCE                =     -5.21
STD. ERR. =           0.05        0.05        0.03 * STD. ERR. OF COVARIANCE =        0.22
VARIANCE     =       22.19       17.41        8.73 * STD. DEV. OF COVARIANCE =       19.51
STD. DEV. =           4.71        4.17        2.95 * CORRELATION COEFFICIENT =      -0.26
KURTOSIS     =        3.34        3.57        3.50 * VECTOR MEAN               =      1.91
SKEWNESS     =        0.38       -0.48        0.59 * VECTOR VARIANCE           =     19.80
                                                   * STD. DEV.                 =      4.45

SAMPLE SIZE = 8201 POINTS.




ANNUAL CURRENT STATISTICS (AVERAGED) - SURFACE
      (CM/SEC)
                        NS          AS       SPEED * *****   NORMAL X ALONGSHORE    *****
                                                   *
MEAN         =       -0.84      -12.03       18.63 * COVARIANCE                =    -13.73
STD. ERR. =           0.12        0.25        0.20 * STD. ERR. OF COVARIANCE =        6.61
VARIANCE     =       76.26      336.17      210.88 * STD. DEV. OF COVARIANCE =      488.35
STD. DEV. =           8.73       18.33       14.52 * CORRELATION COEFFICIENT =      -0.09
KURTOSIS     =       15.77        6.97       18.63 * VECTOR MEAN               =     12.06
SKEWNESS     =        1.41       -1.06        2.59 * VECTOR VARIANCE           =    206.22
                                                   * STD. DEV.                 =     14.36

SAMPLE SIZE = 5453 POINTS.
```

TABLE 22

```
EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATICNAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE -    76

ANNUAL CURRENT STATISTICS (AVERAGED)   -10.0m
      (CM/SEC)
                      NS          AS      SPEED * *****   NORMAL X ALONGSHORE      *****
                                                *
MEAN          =      2.14       -2.49     15.53 * COVARIANCE                  =     46.06
STD. ERR. =          0.12        0.23      0.15 * STD. ERR. OF COVARIANCE =          6.11
VARIANCE    =       70.34      274.34    114.20 * STD. DEV. OF COVARIANCE =        441.92
STD. DEV. =          8.39       16.56     10.69 * CORRELATION COEFFICIENT =          0.33
KURTOSIS    =       60.19        4.45     45.07 * VECTOR MEAN                 =      3.29
SKEWNESS    =       -1.86        0.09      2.83 * VECTOR VARIANCE             =    172.34
                                                * STD. DEV.                   =     13.13

SAMPLE SIZE = 5230 POINTS.



EVANS-HAMILTON OCEANOGRAPHIC DATA REDUCTION -

NATICNAL MARINE FISHERIES BUCCANEER DATA ANALYSIS - DATE -    76

ANNUAL CURRENT STATISTICS (AVERAGED)   -17.7m
      (CM/SEC)
                      NS          AS      SPEED * *****   NORMAL X ALONGSHORE      *****
                                                *
MEAN          =      0.70       -1.12     11.95 * COVARIANCE                  =     26.85
STD. ERR. =          0.08        0.23      0.16 * STD. ERR. OF COVARIANCE =          1.53
VARIANCE    =       24.02      217.82    100.71 * STD. DEV. OF COVARIANCE =         98.43
STD. DEV. =          4.90       14.76     10.04 * CORRELATION COEFFICIENT =          0.37
KURTOSIS    =        3.83        4.91      7.22 * VECTOR MEAN                 =      1.32
SKEWNESS    =       -0.04       -0.75      1.83 * VECTOR VARIANCE             =    120.92
                                                * STD. DEV.                   =     11.00

SAMPLE SIZE = 4117 POINTS.
```

TABLE 23

Table 24
Data Catalogue

Sensor	Periods of Useable Data		
Wind			
	1300 December 18, 1975	through	2300 January 17, 1976
	1100 January 20, 1976	through	2100 February 8, 1976
	1100 February 13, 1976	through	1700 May 10, 1976
	0900 May 17, 1976	through	0200 July 6, 1976
	1500 July 12, 1976	through	0900 August 11, 1976
	1300 August 13, 1976	through	1200 November 16, 1976
	1100 November 29, 1976	through	1000 December 29, 1976
Current Meter No. 1 (-4.0m)			
	1400 March 23, 1976	through	1900 April 17, 1976
	1100 June 10, 1976	through	0900 December 29, 1976
Current Meter No. 2 (-10.0m)			
	1200 December 18, 1975	through	0000 December 30, 1975
	1100 January 16, 1975	through	0000 April 14, 1976
	1800 April 14, 1976	through	2000 June 9, 1976
	1100 June 10, 1976	through	0100 August 2, 1976
	1200 September 8, 1976	through	0600 October 11, 1976
Current Meter No. 3 (-17.7m)			
	1400 March 22, 1976	through	2000 March 27, 1976
	1600 May 18, 1976	through	2000 June 9, 1976
	1100 June 10, 1976	through	1600 August 2, 1976
	1300 August 13, 1976	through	2000 October 29, 1976
	1000 April 8, 1976	through	1100 May 15, 1976

FIGURE 1

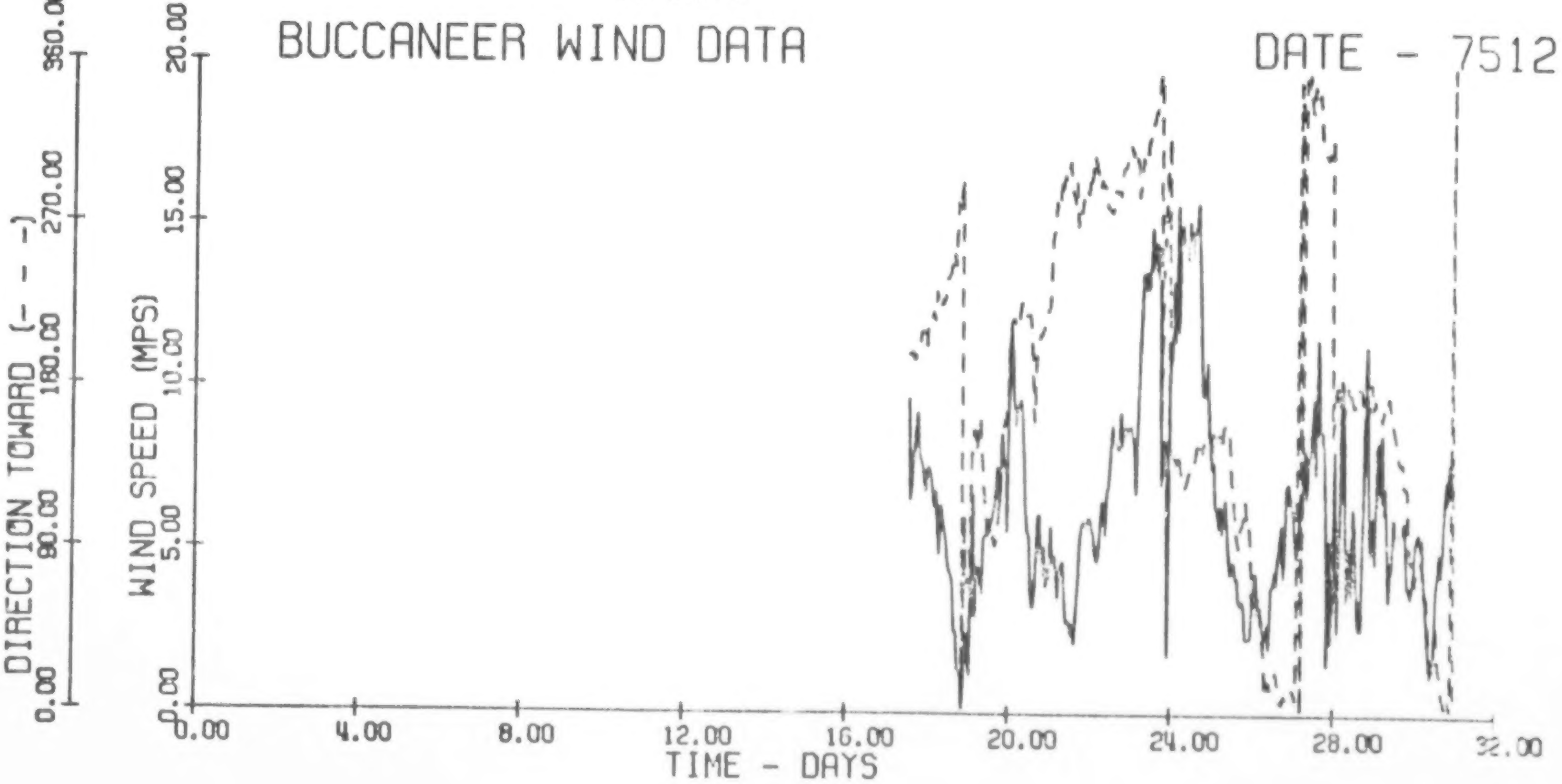
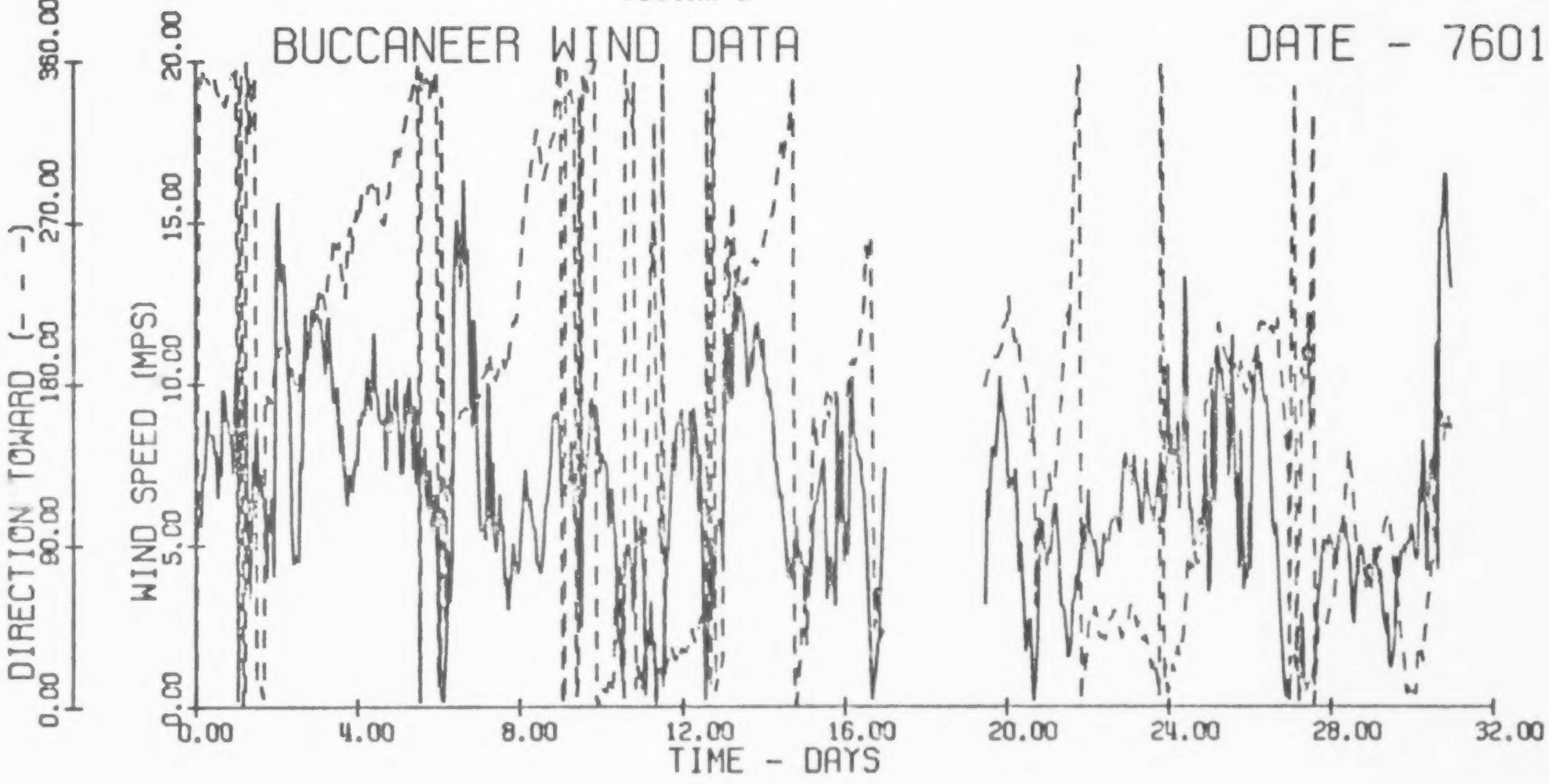

BUCCANEER WIND DATA
DATE - 7512
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 2


BUCCANEER WIND DATA

DATE - 7601

FIGURE 3

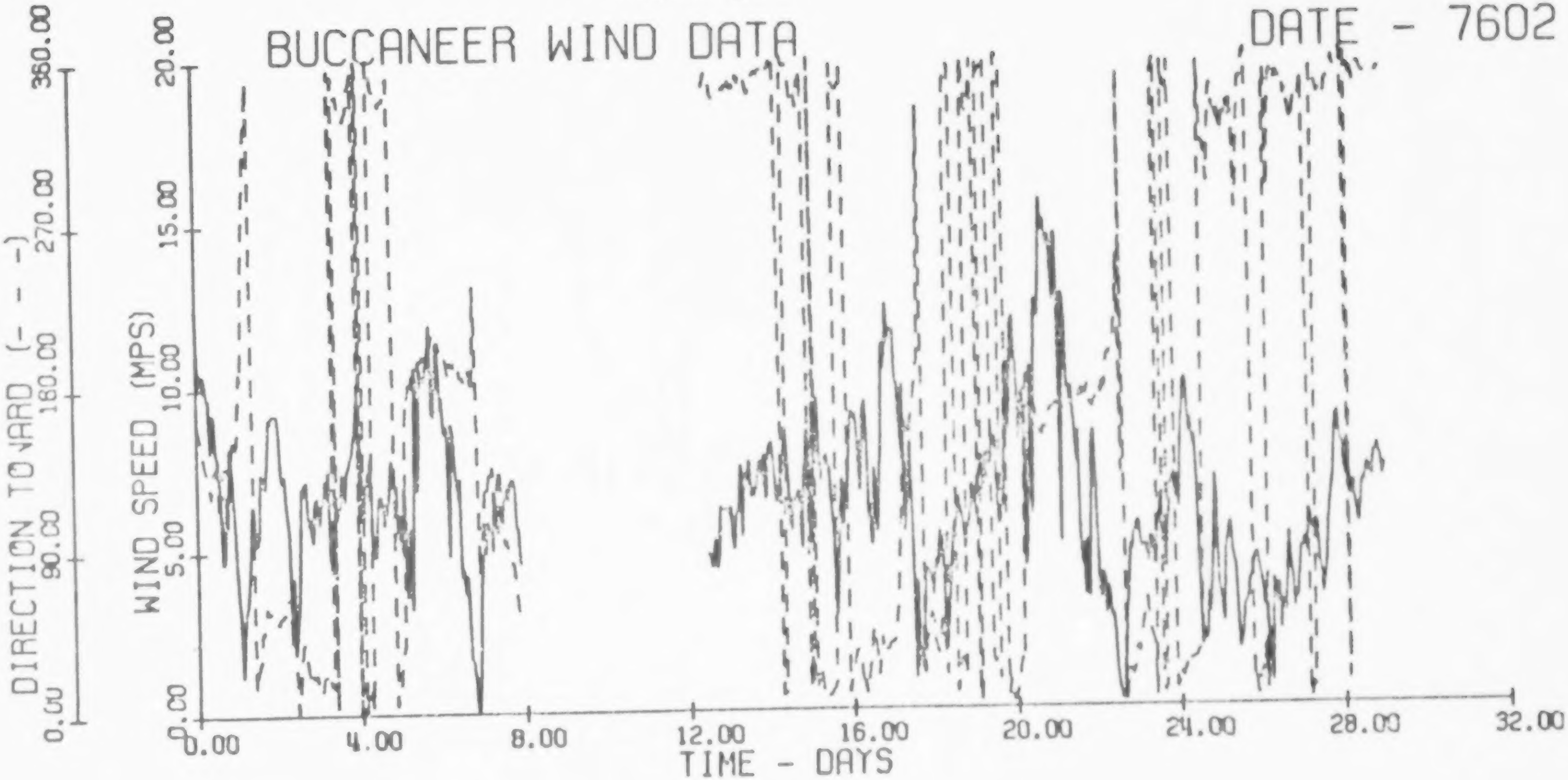

BUCCANEER WIND DATA
DATE - 7602
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 4

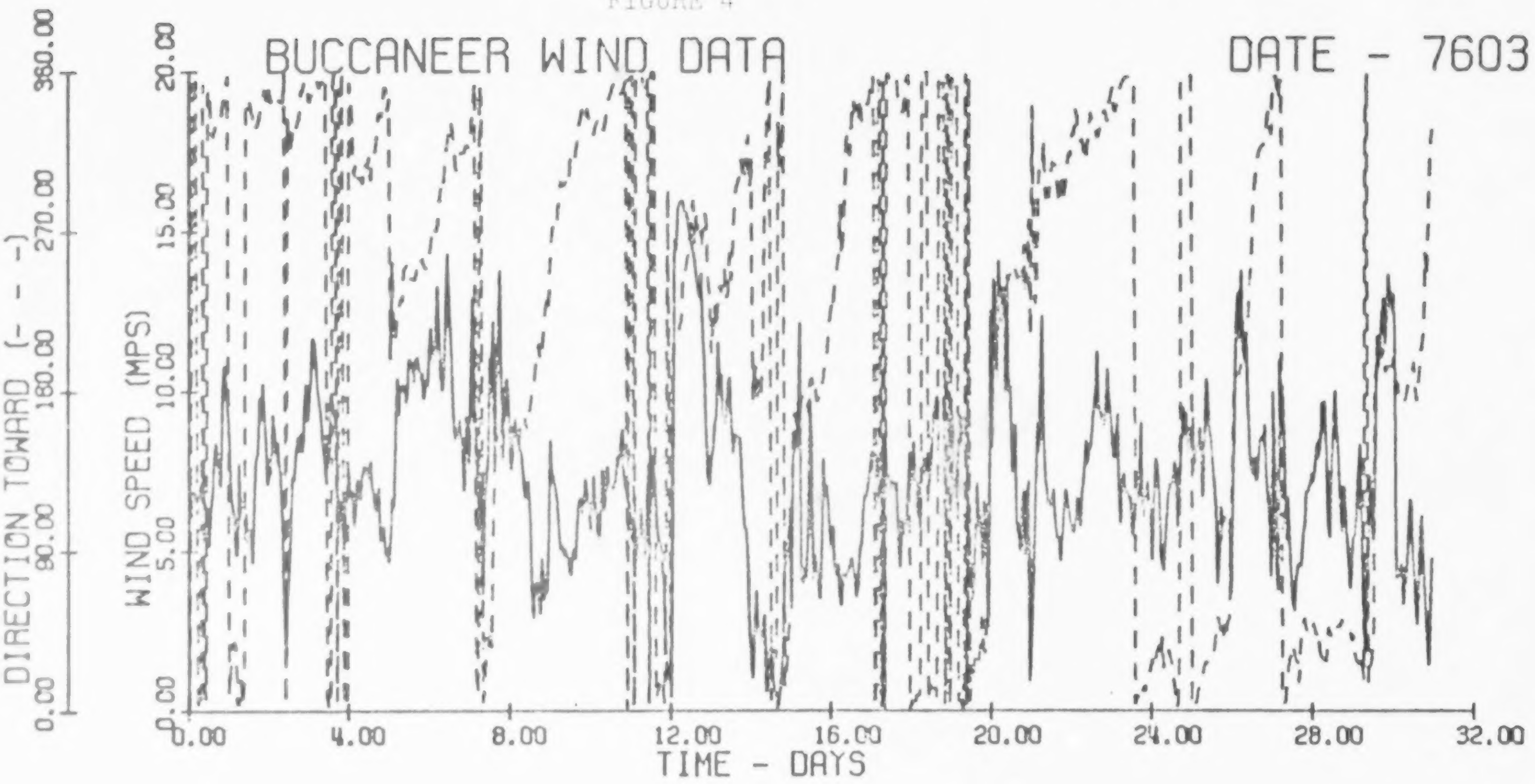

BUCCANEER WIND DATA
DATE - 7603
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 5

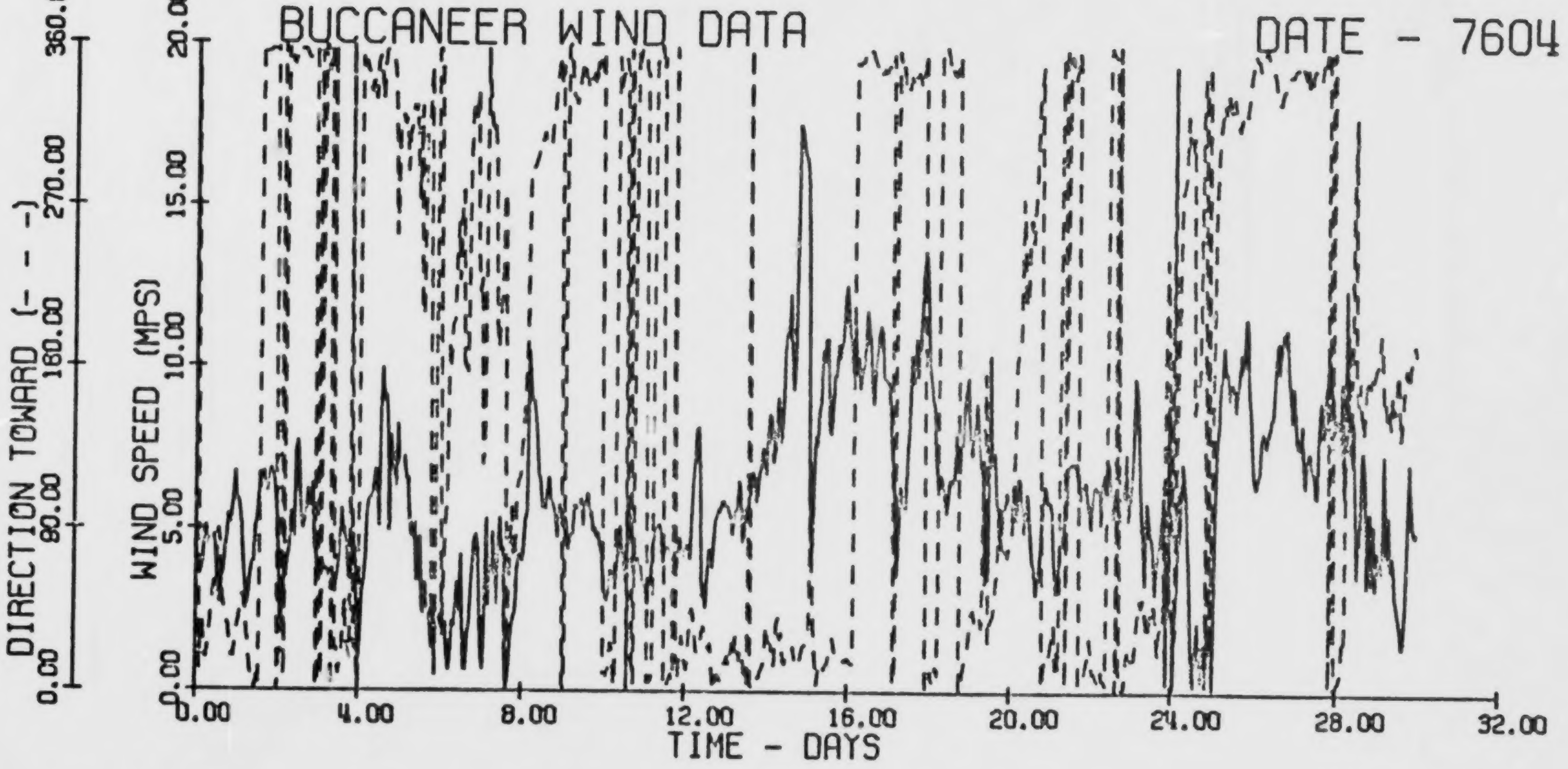

BUCCANEER WIND DATA
DATE - 7604
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
TIME - DAYS
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00

FIGURE 6

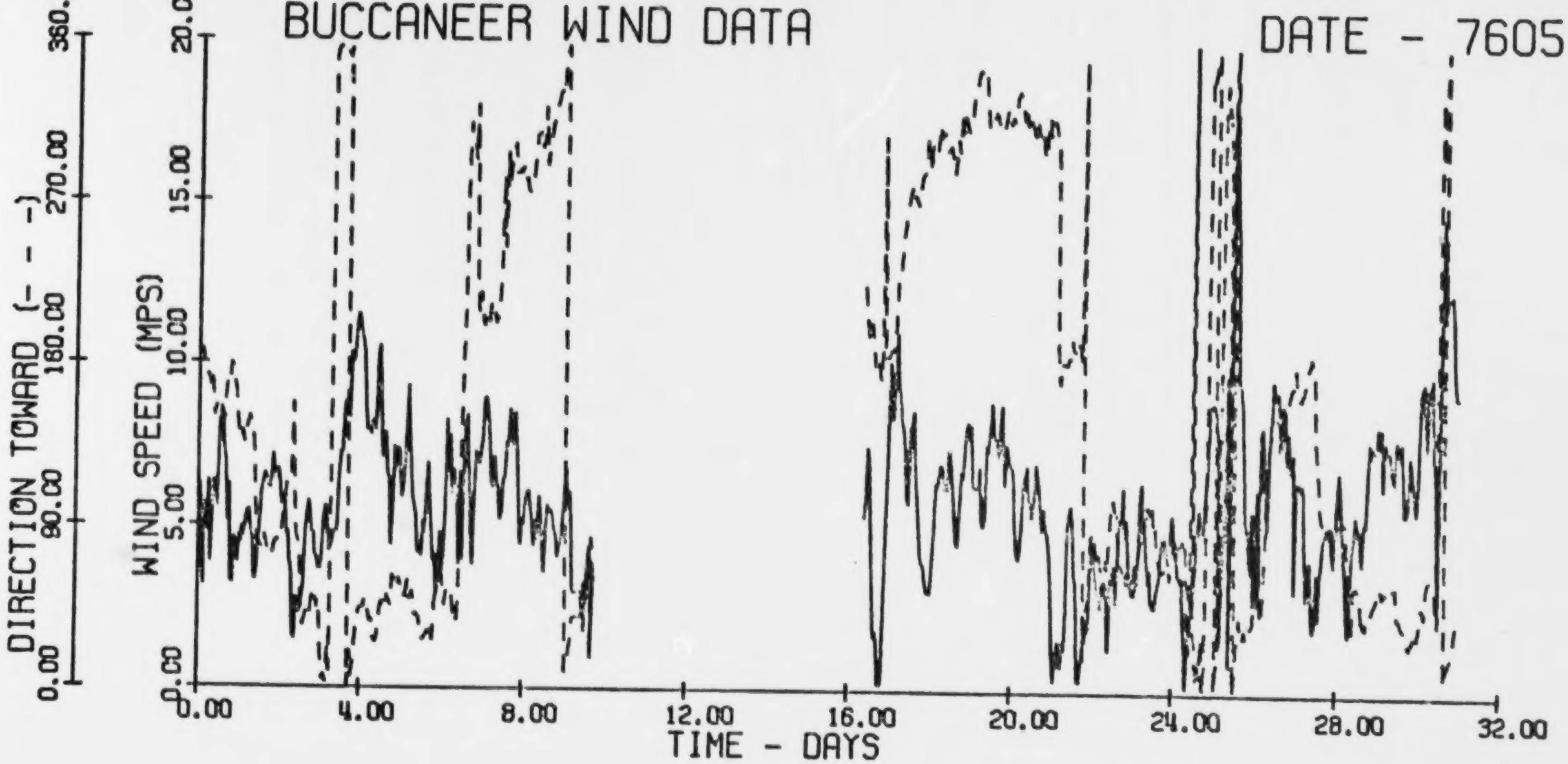

BUCCANEER WIND DATA
DATE - 7605
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 7

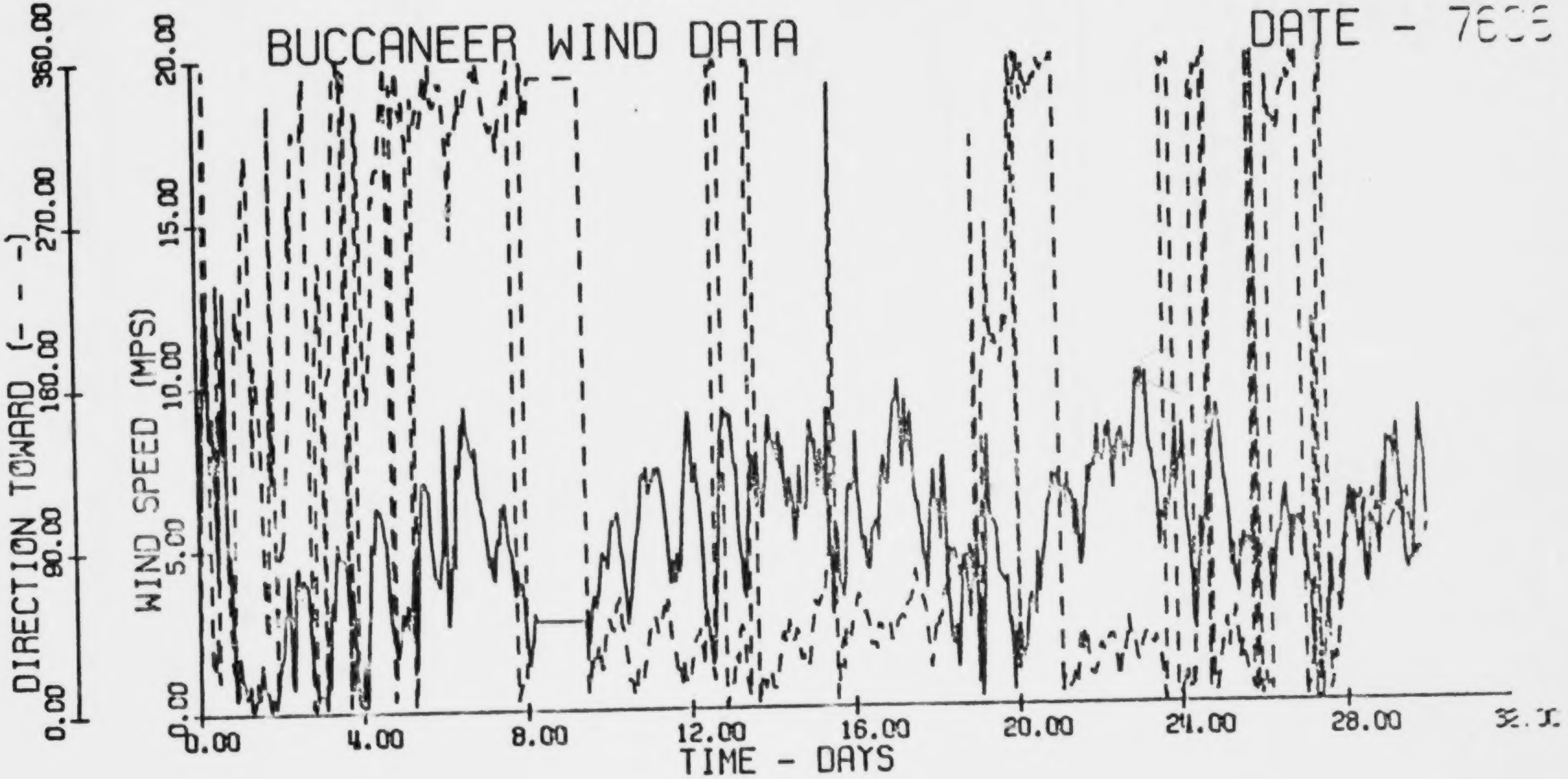

BUCCANEER WIND DATA
DATE - 7606
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 8

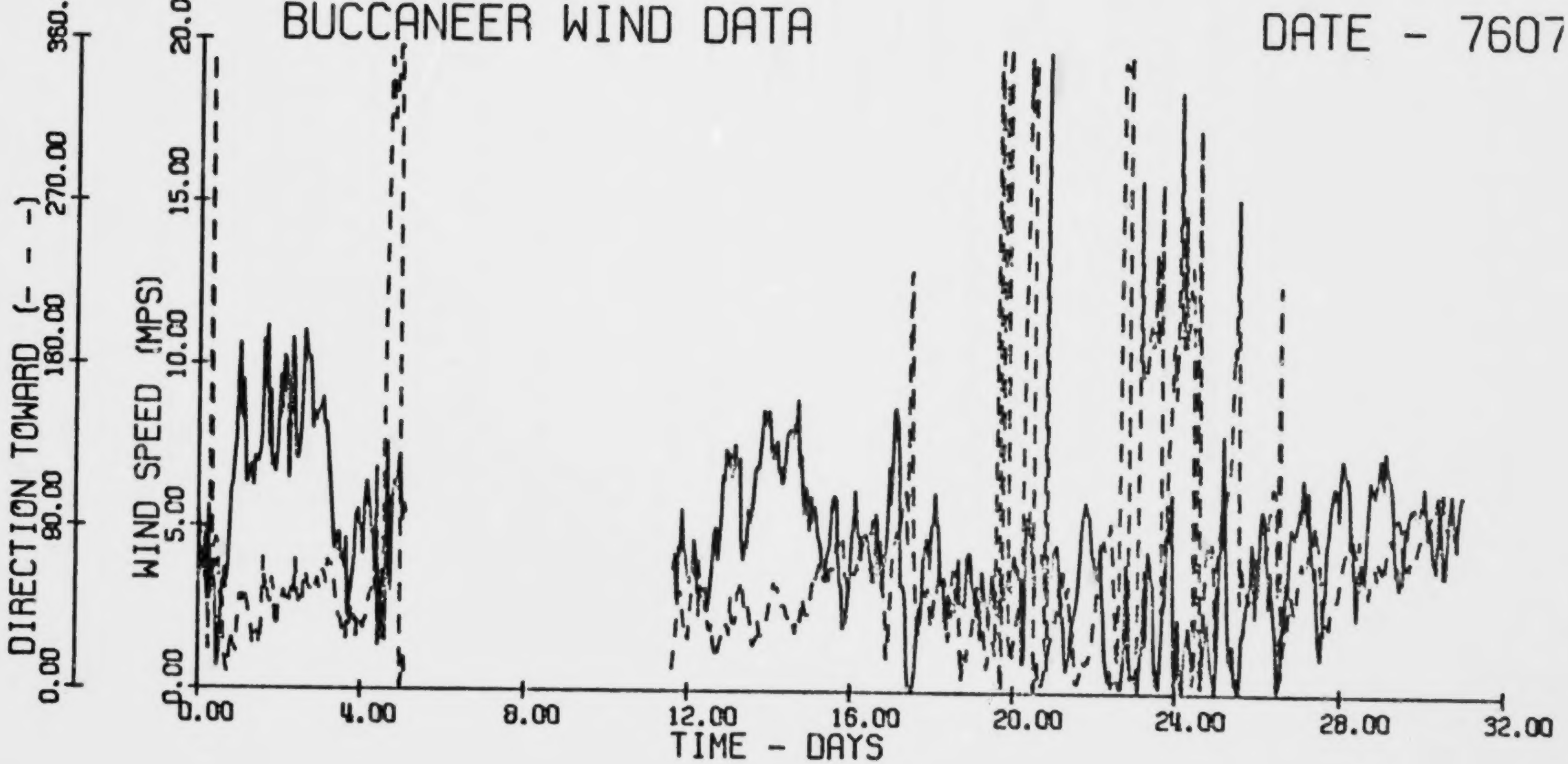

BUCCANEER WIND DATA
DATE - 7607
DIRECTION TOWARD (- - -)
0.00
80.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 9

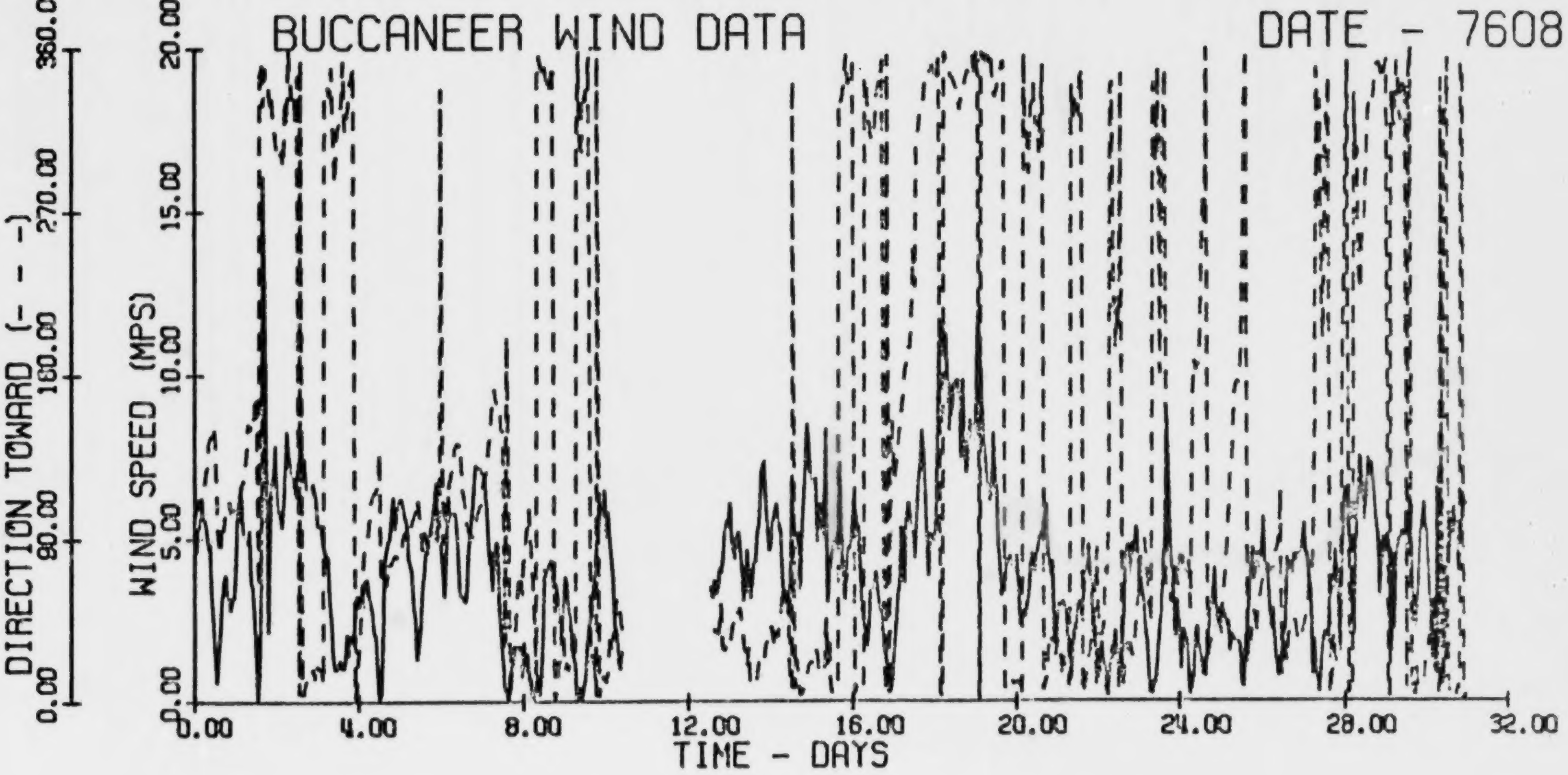

BUCCANEER WIND DATA
DATE - 7608
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 10

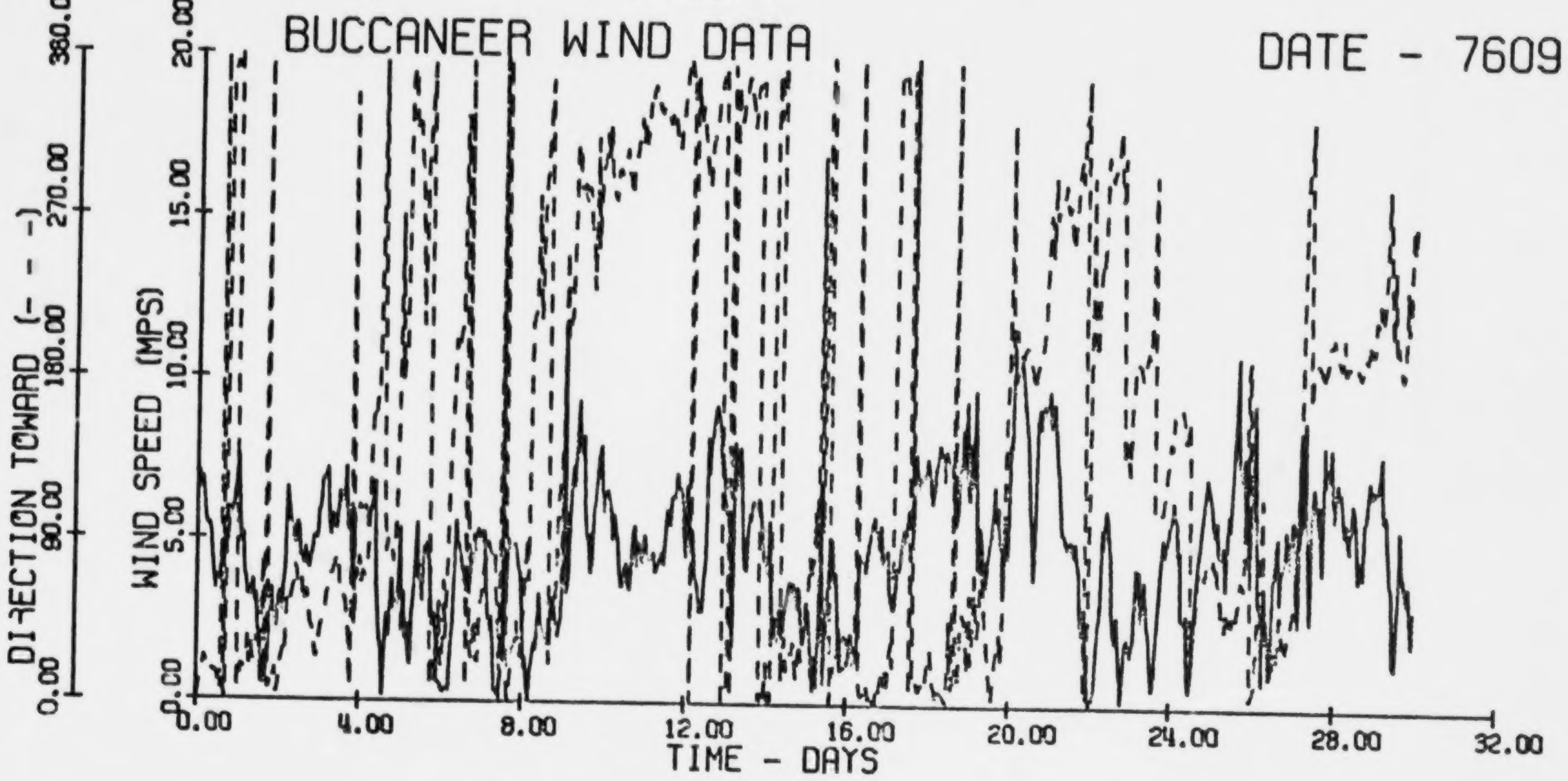

BUCCANEER WIND DATA
DATE - 7609
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
TIME - DAYS
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00

FIGURE 11

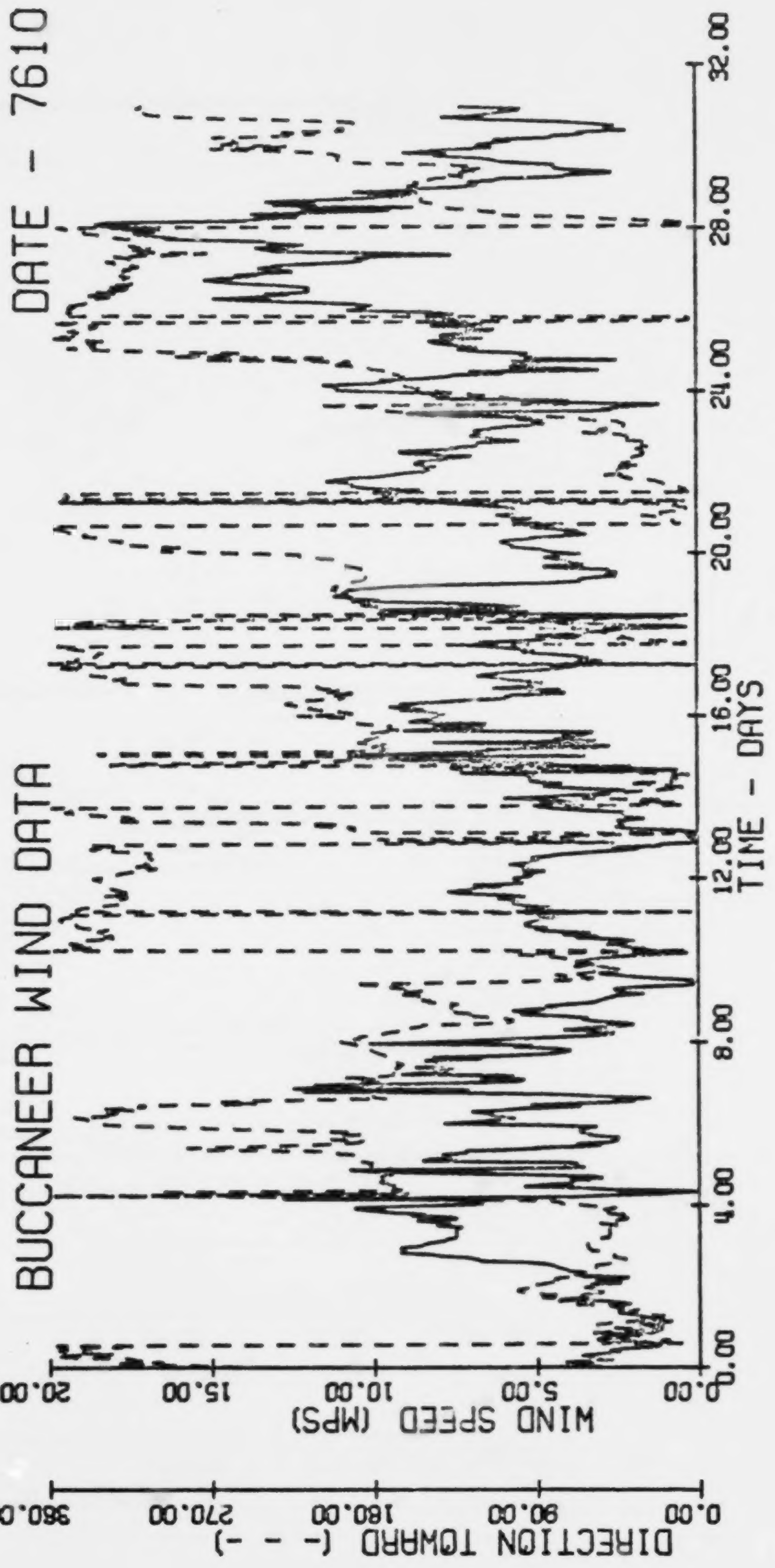

BUCCANEER WIND DATA
DATE - 7610
TIME - DAYS
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00

FIGURE 12

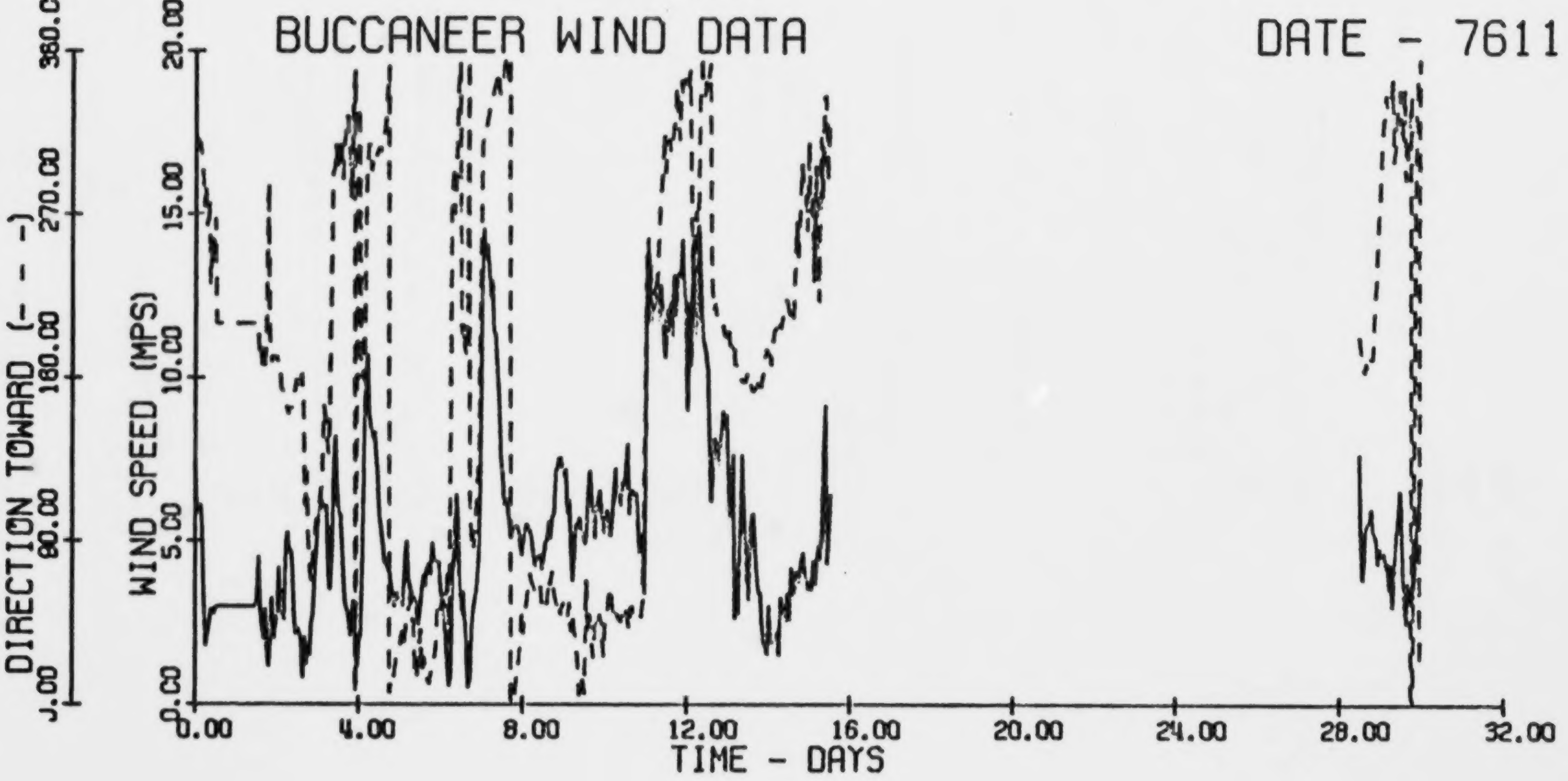

BUCCANEER WIND DATA
DATE - 7611
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 13

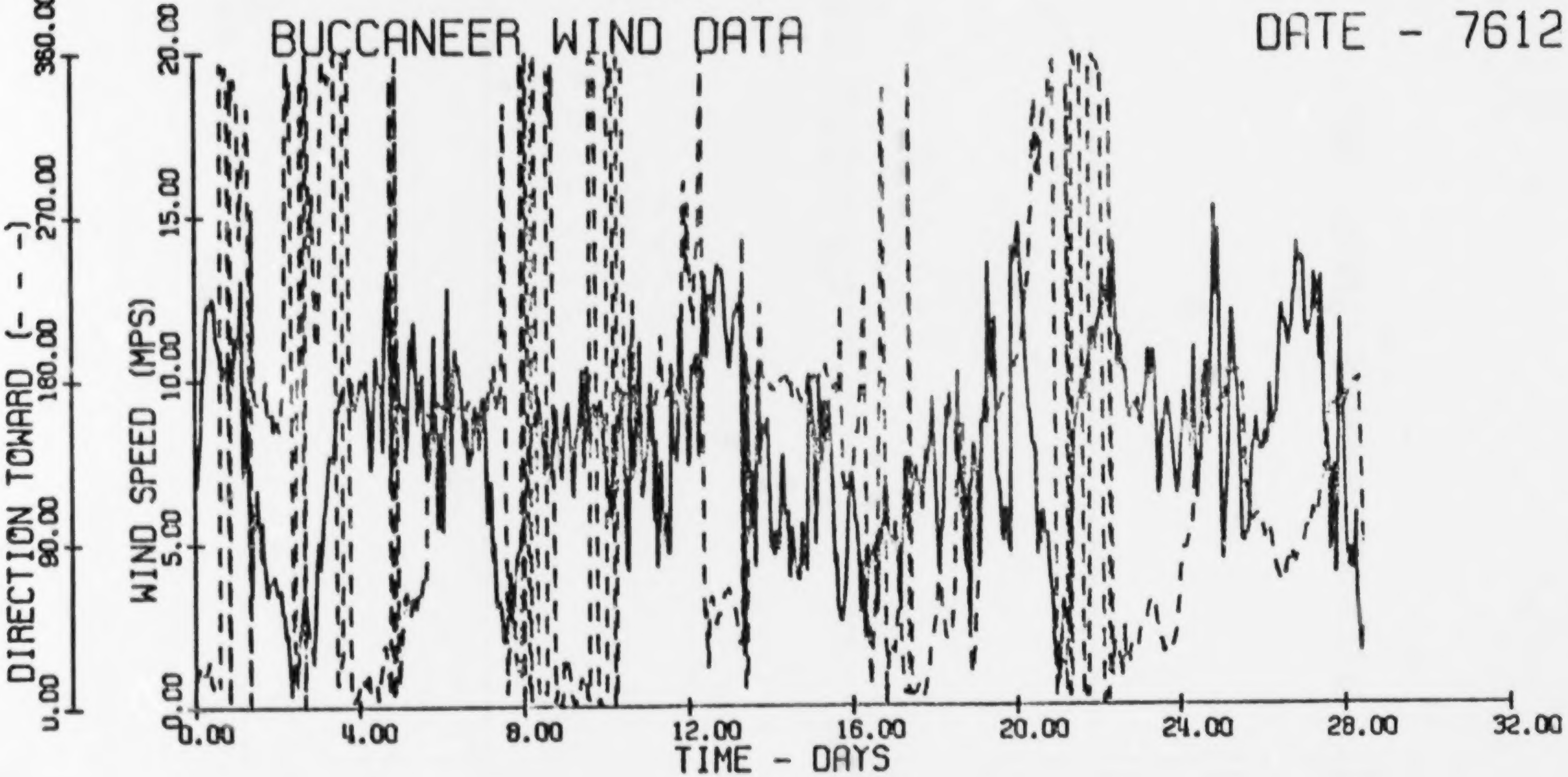

BUCCANEER WIND DATA
DATE - 7612
DIRECTION TOWARD (- - -)
0.00
90.00
180.00
270.00
360.00
WIND SPEED (MPS)
0.00
5.00
10.00
15.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 14

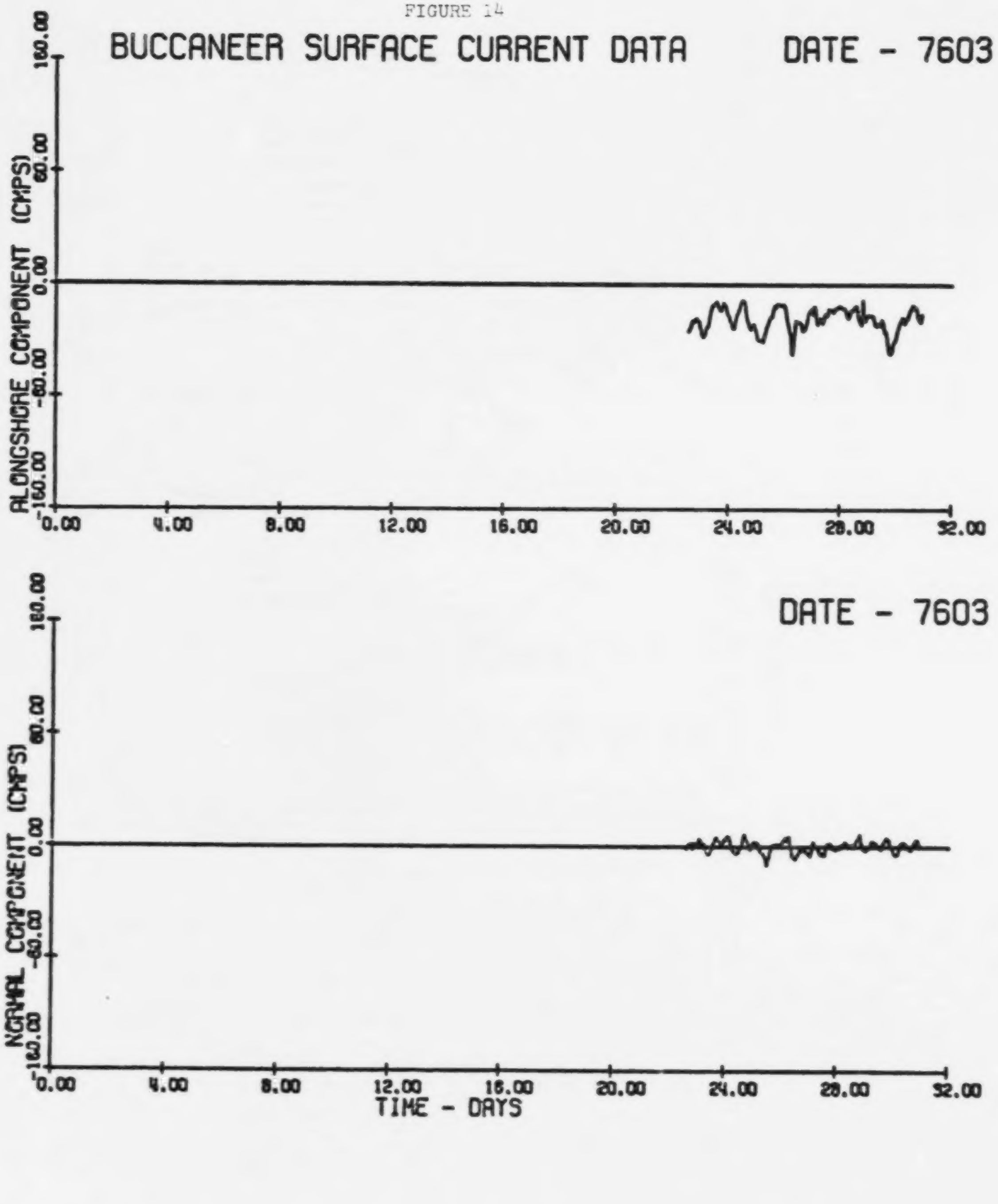

BUCCANEER SURFACE CURRENT DATA
DATE - 7603
ALONGSHORE COMPONENT (CMPS)
180.00
60.00
0.00
-60.00
-180.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7603
NORMAL COMPONENT (CMPS)
180.00
60.00
0.00
-60.00
-180.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 15

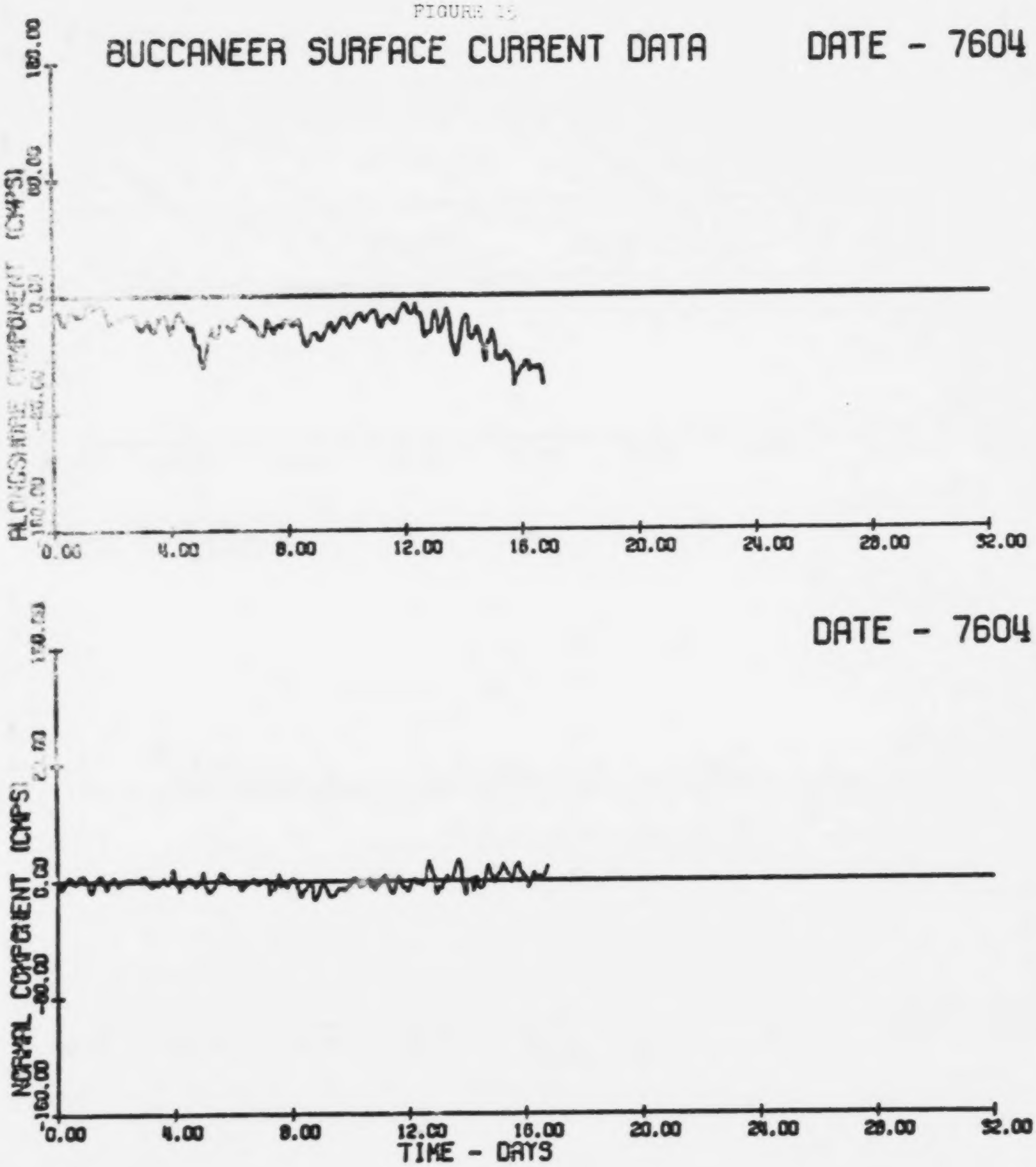

BUCCANEER SURFACE CURRENT DATA
DATE - 7604
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7604
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 16

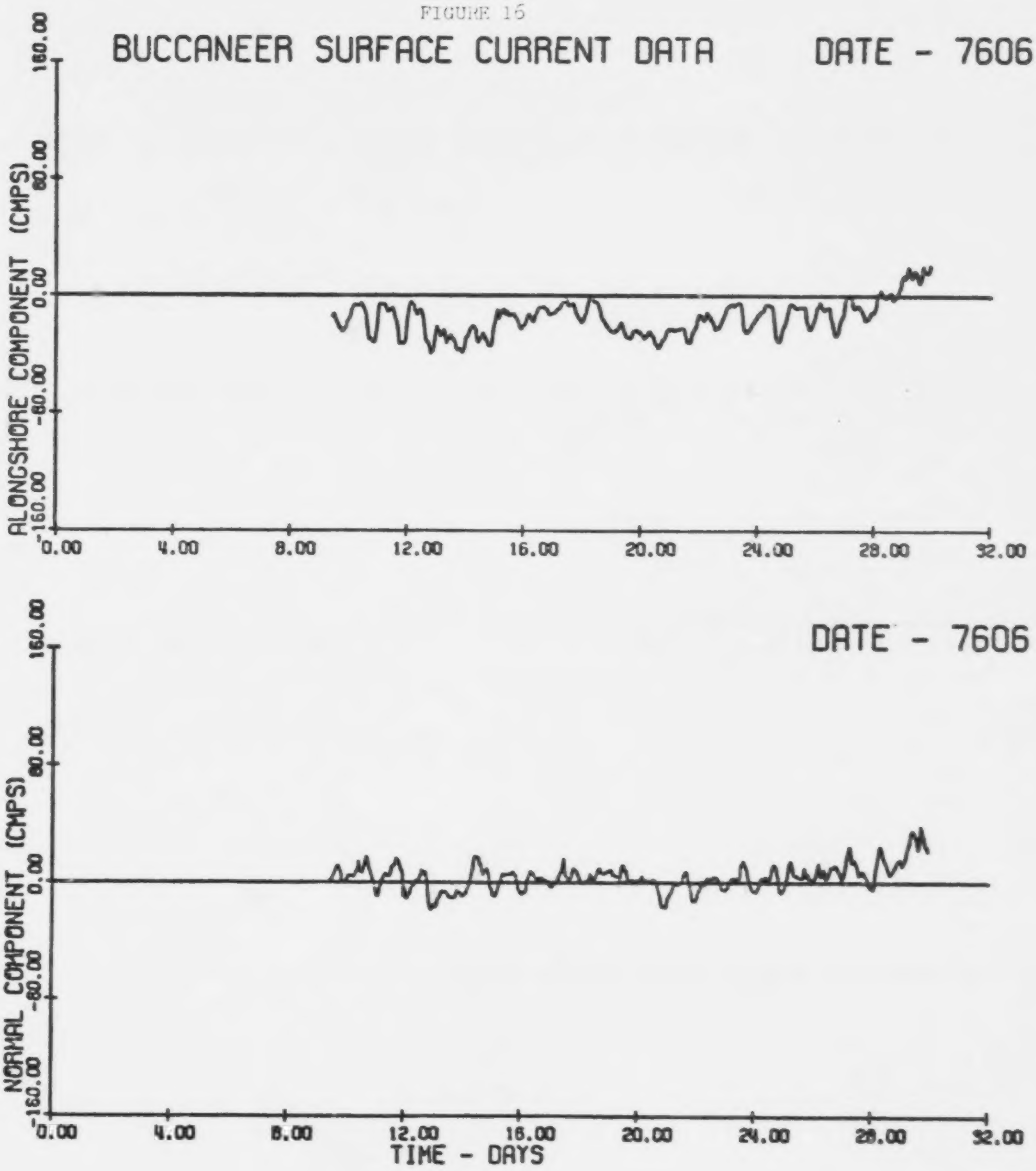
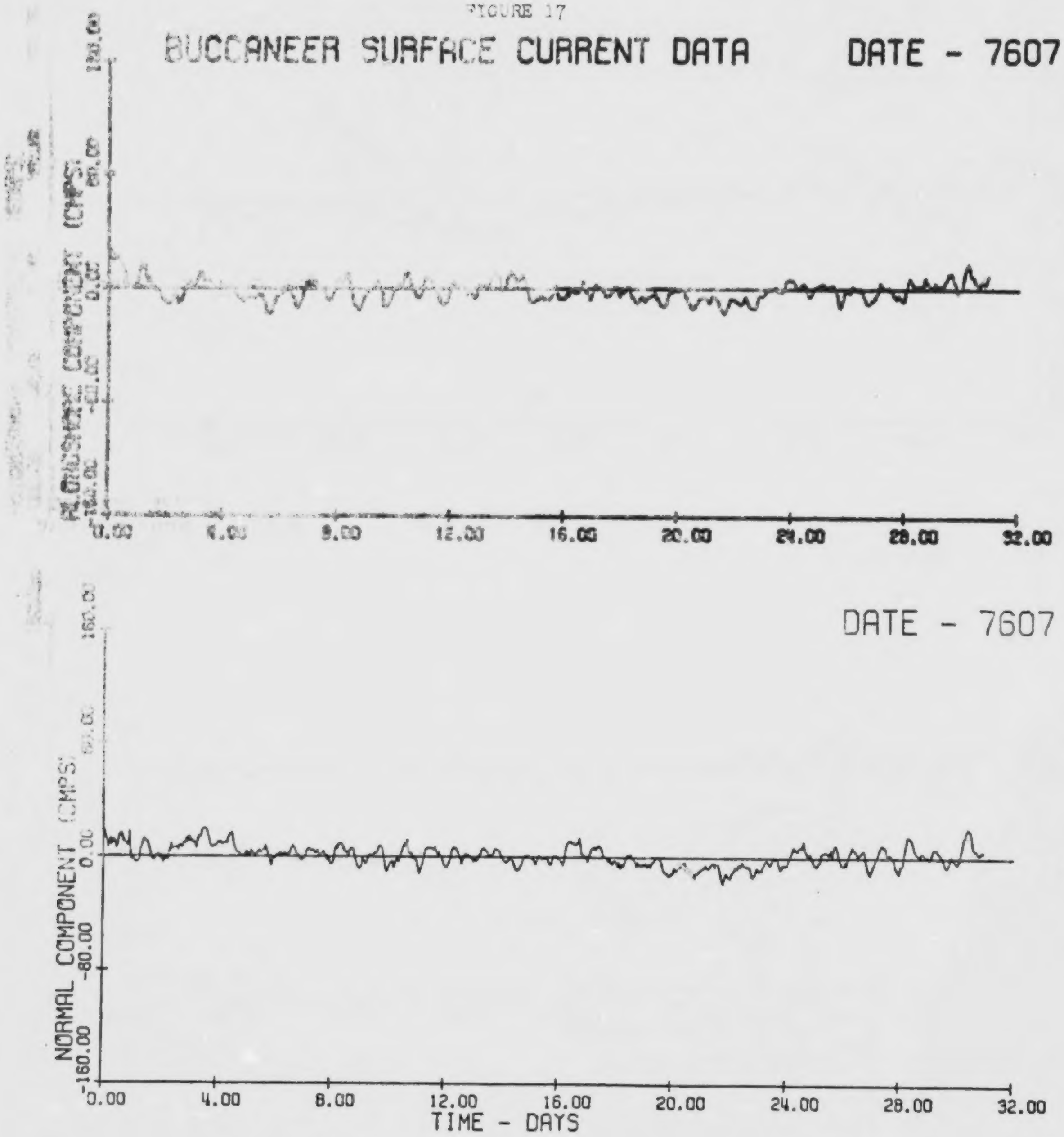

BUCCANEER SURFACE CURRENT DATA
DATE - 7606
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7606
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 17



BUCCANEER SURFACE CURRENT DATA DATE - 7607

FIGURE 18

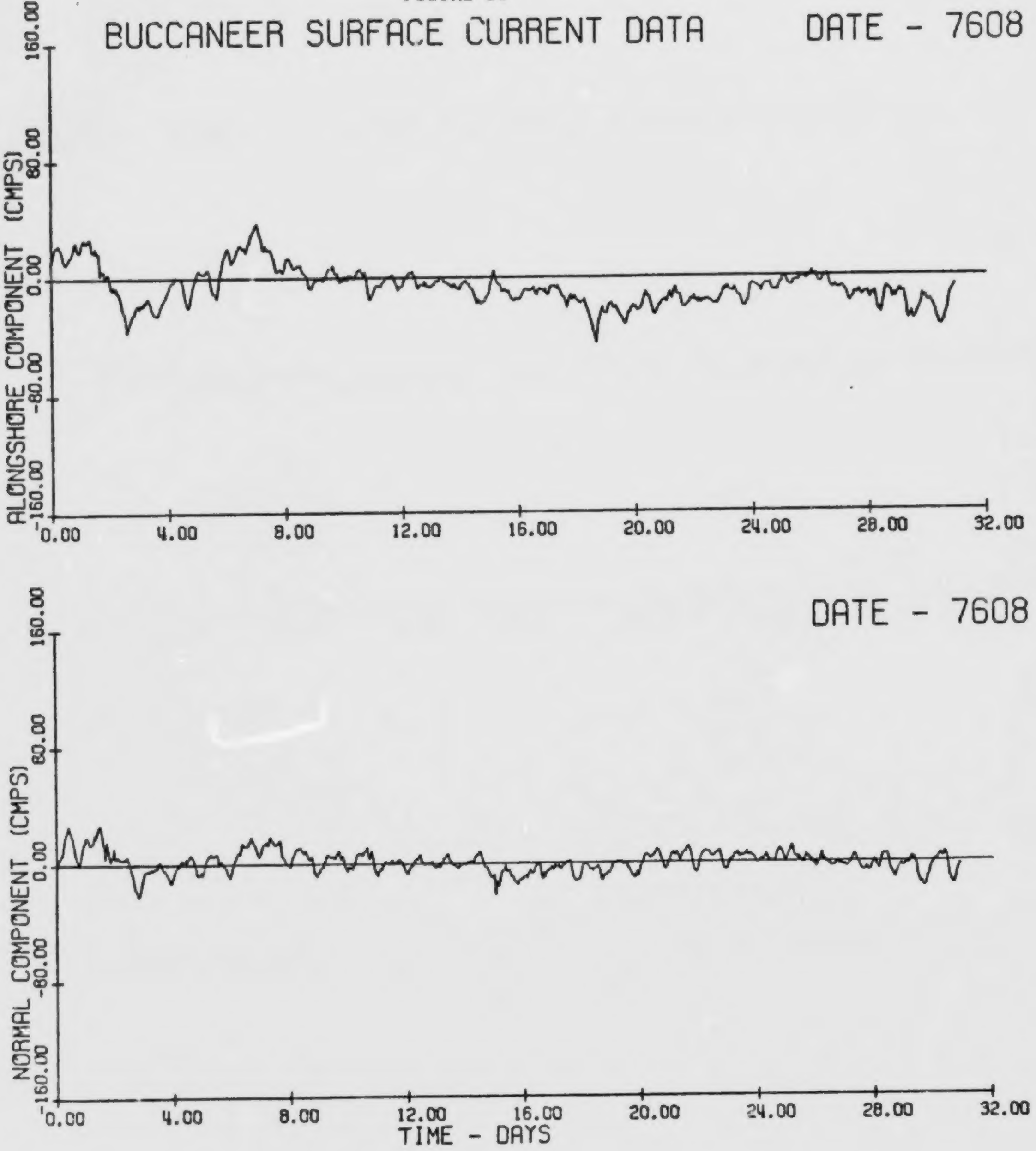

BUCCANEER SURFACE CURRENT DATA
DATE - 7608
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7608
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 19

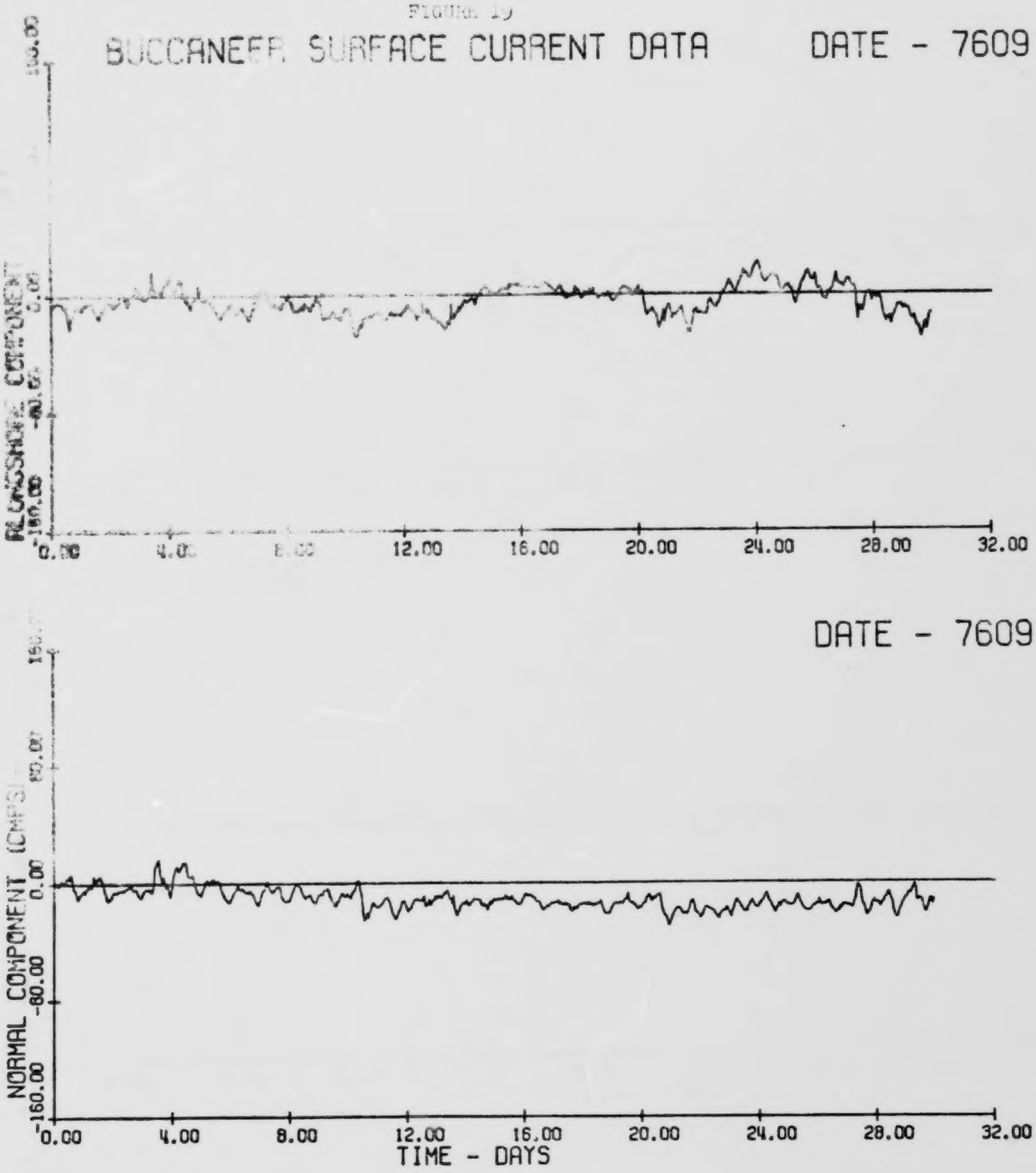

BUCCANEER SURFACE CURRENT DATA
DATE - 7609
ALONGSHORE COMPONENT
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7609
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 20

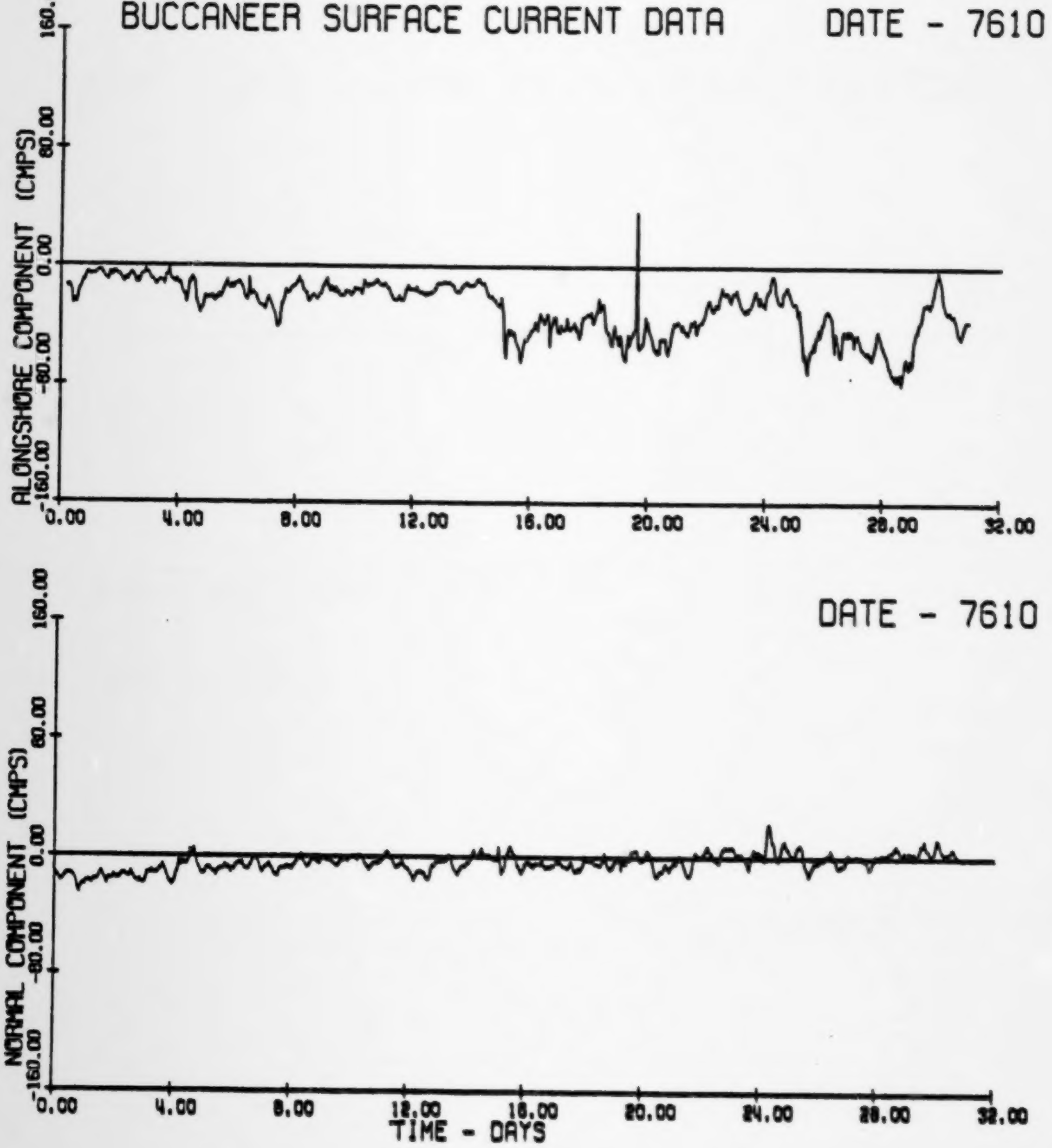

BUCCANEER SURFACE CURRENT DATA
DATE - 7610
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7610
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 21

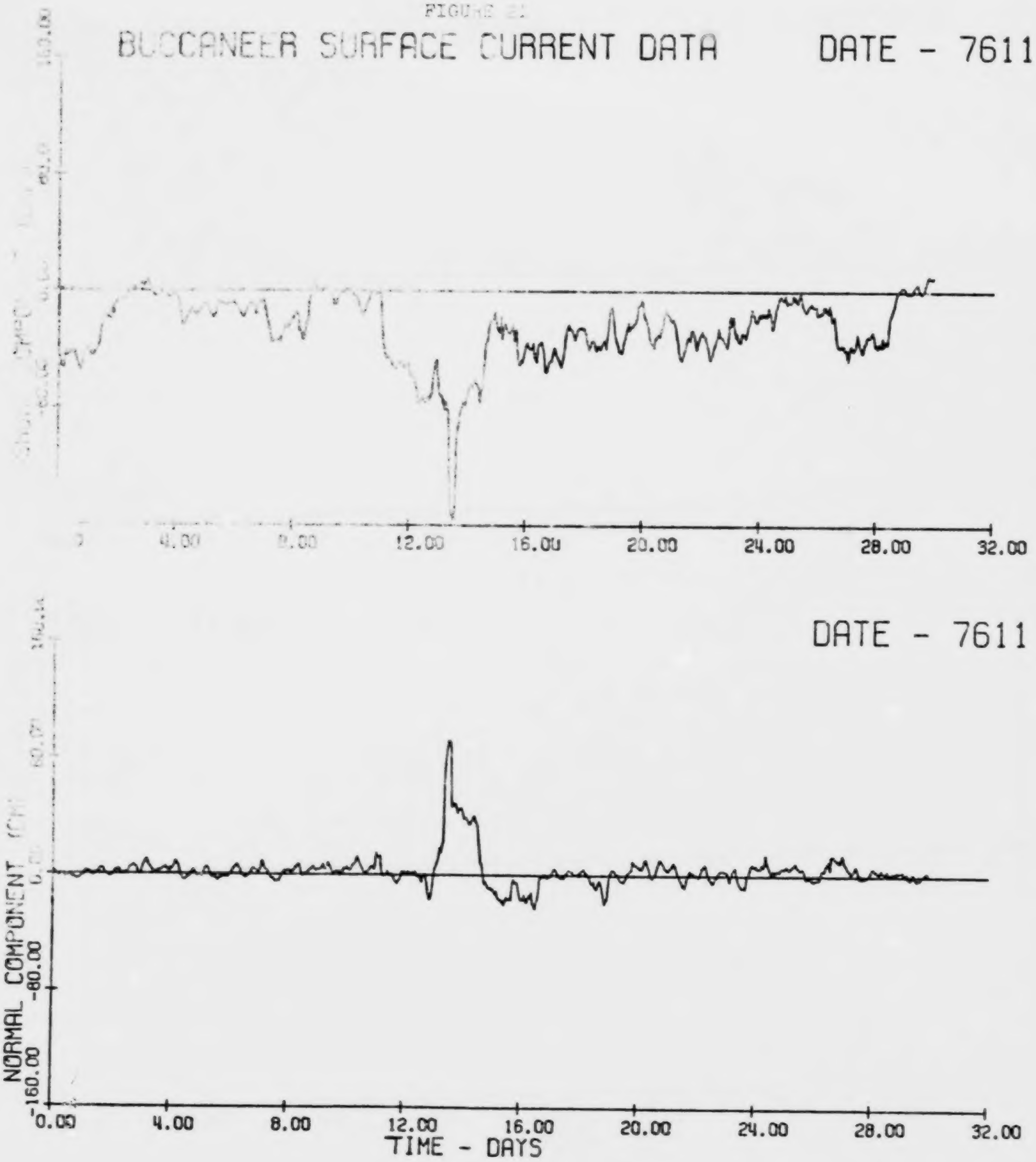

BUCCANEER SURFACE CURRENT DATA
DATE - 7611
160.00
80.00
0.00
-80.00
0
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7611
NORMAL COMPONENT (CM
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 22

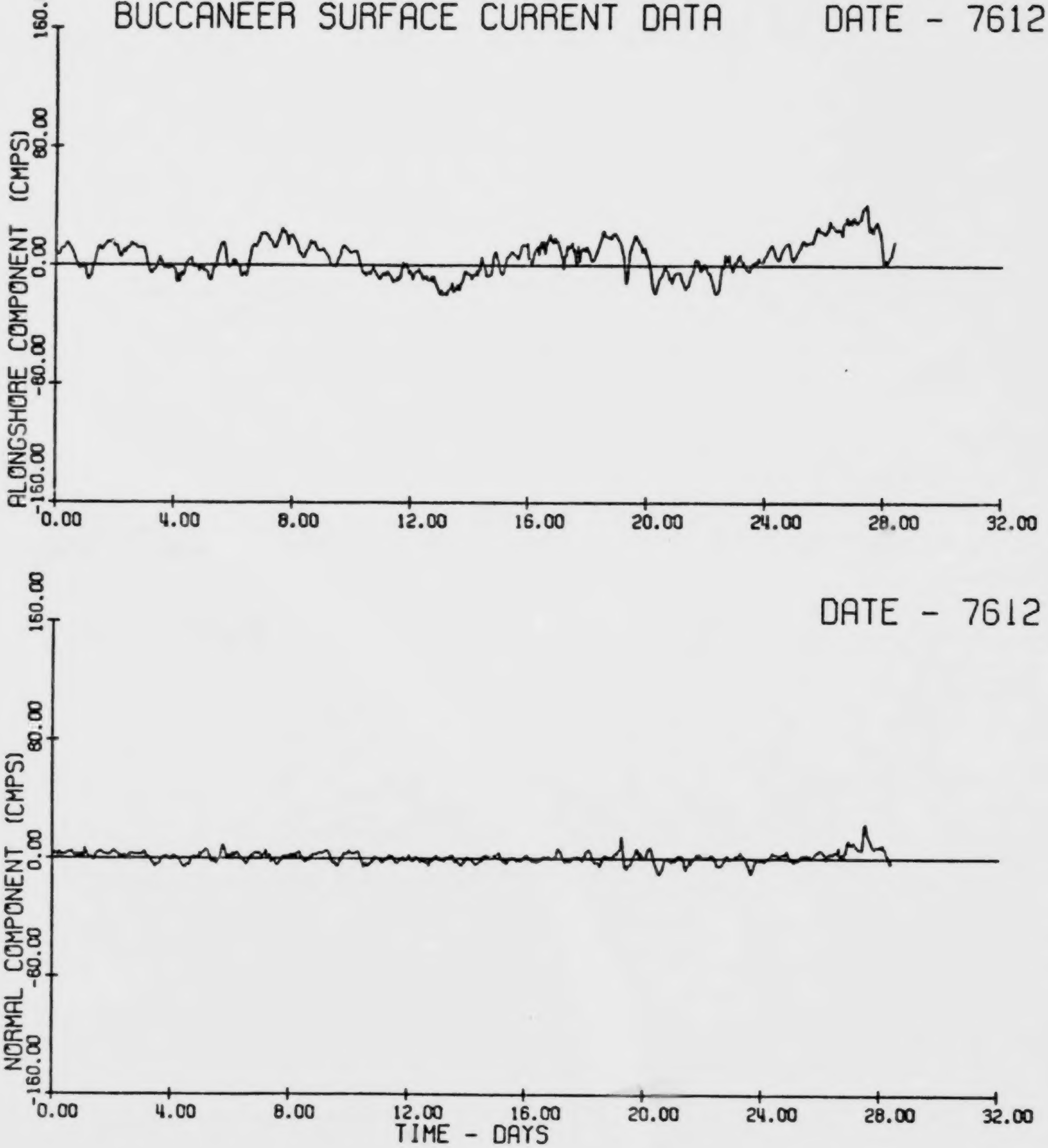

BUCCANEER SURFACE CURRENT DATA
DATE - 7612
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7612
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 23

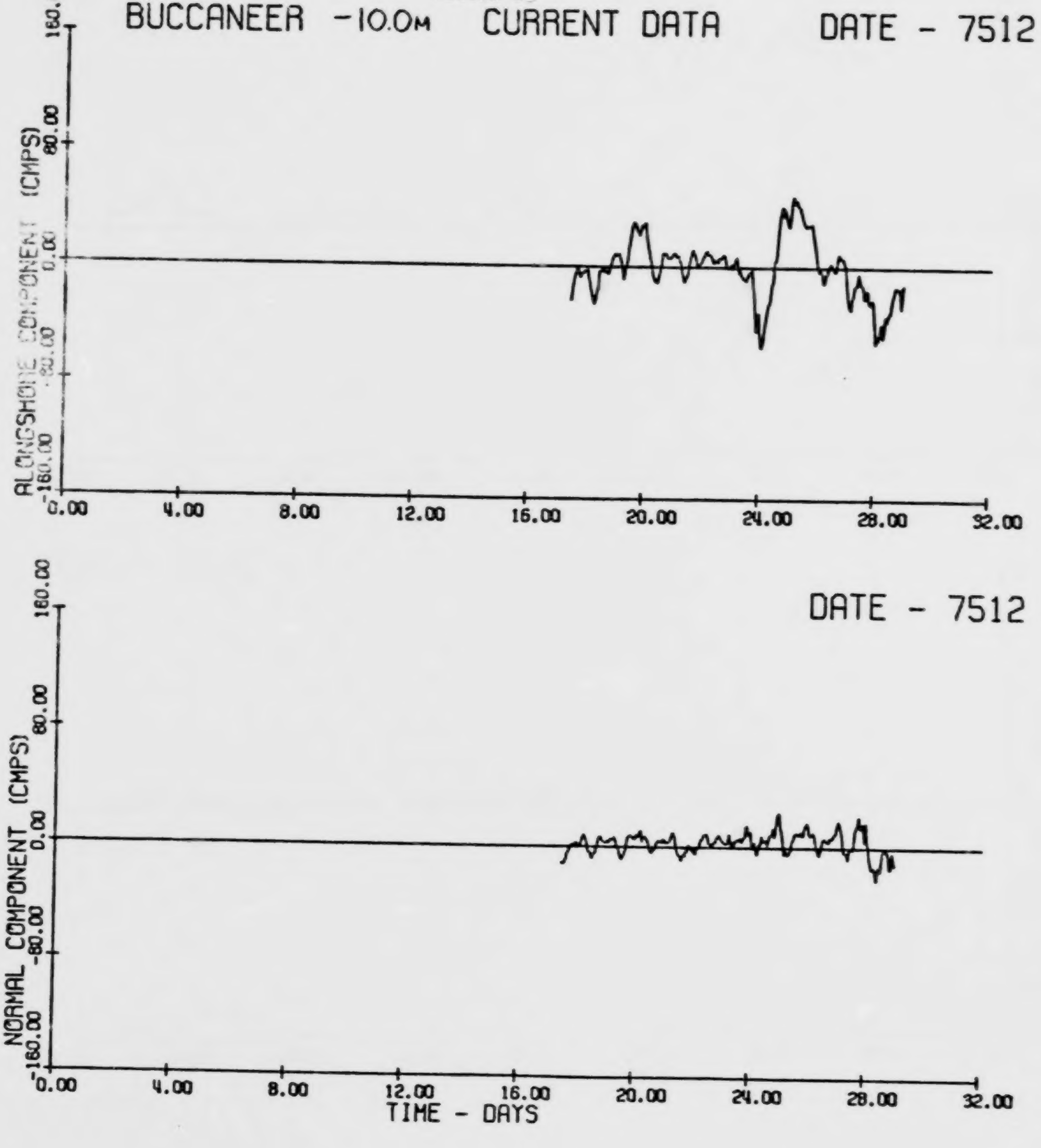

BUCCANEER -10.0M CURRENT DATA
DATE - 7512
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7512
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 24

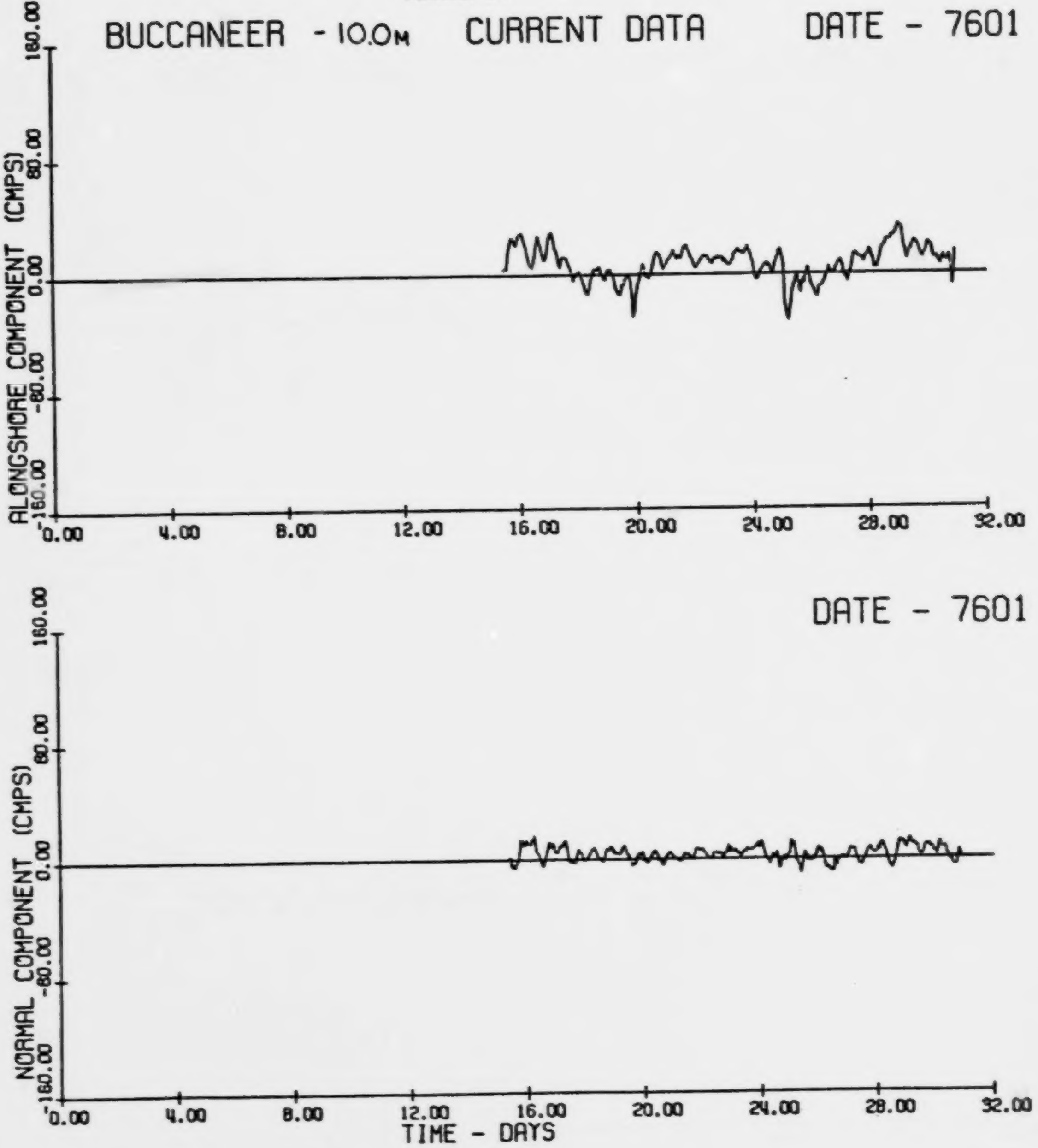

BUCCANEER - 10.0M CURRENT DATA
DATE - 7601
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7601
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 25

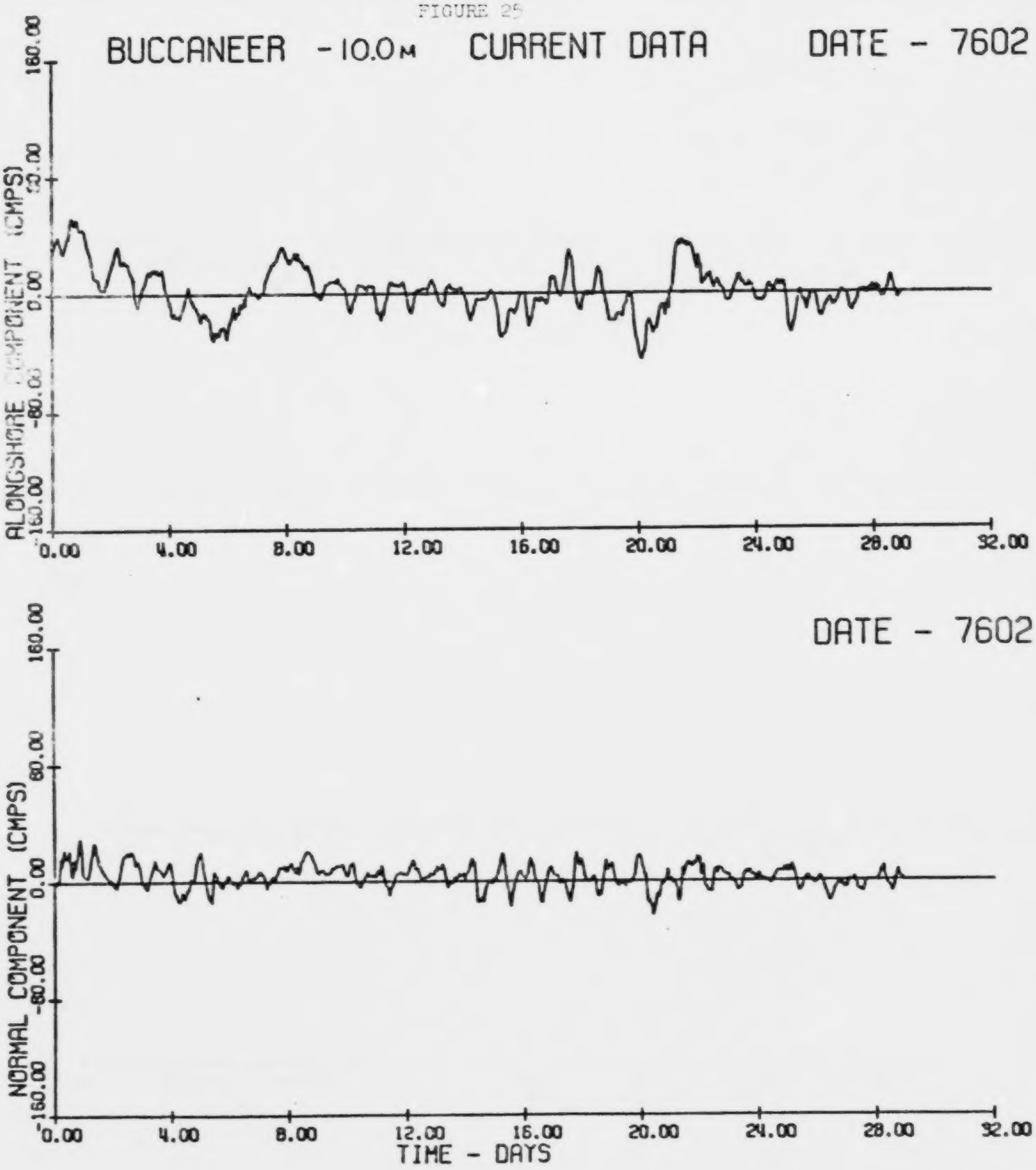

BUCCANEER -10.0M CURRENT DATA
DATE - 7602
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7602
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 26

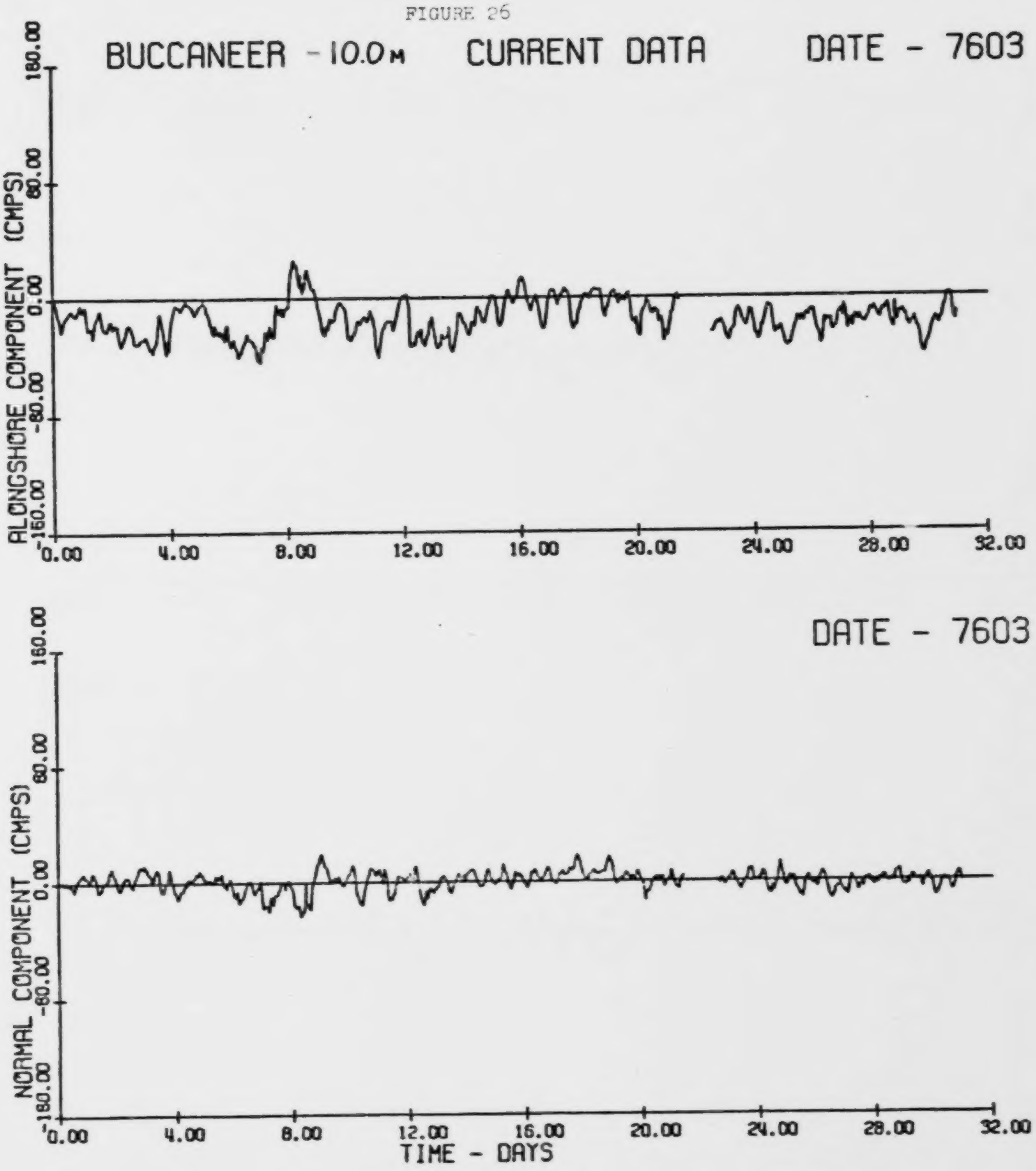

BUCCANEER -10.0M CURRENT DATA
DATE - 7603
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7603
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 27

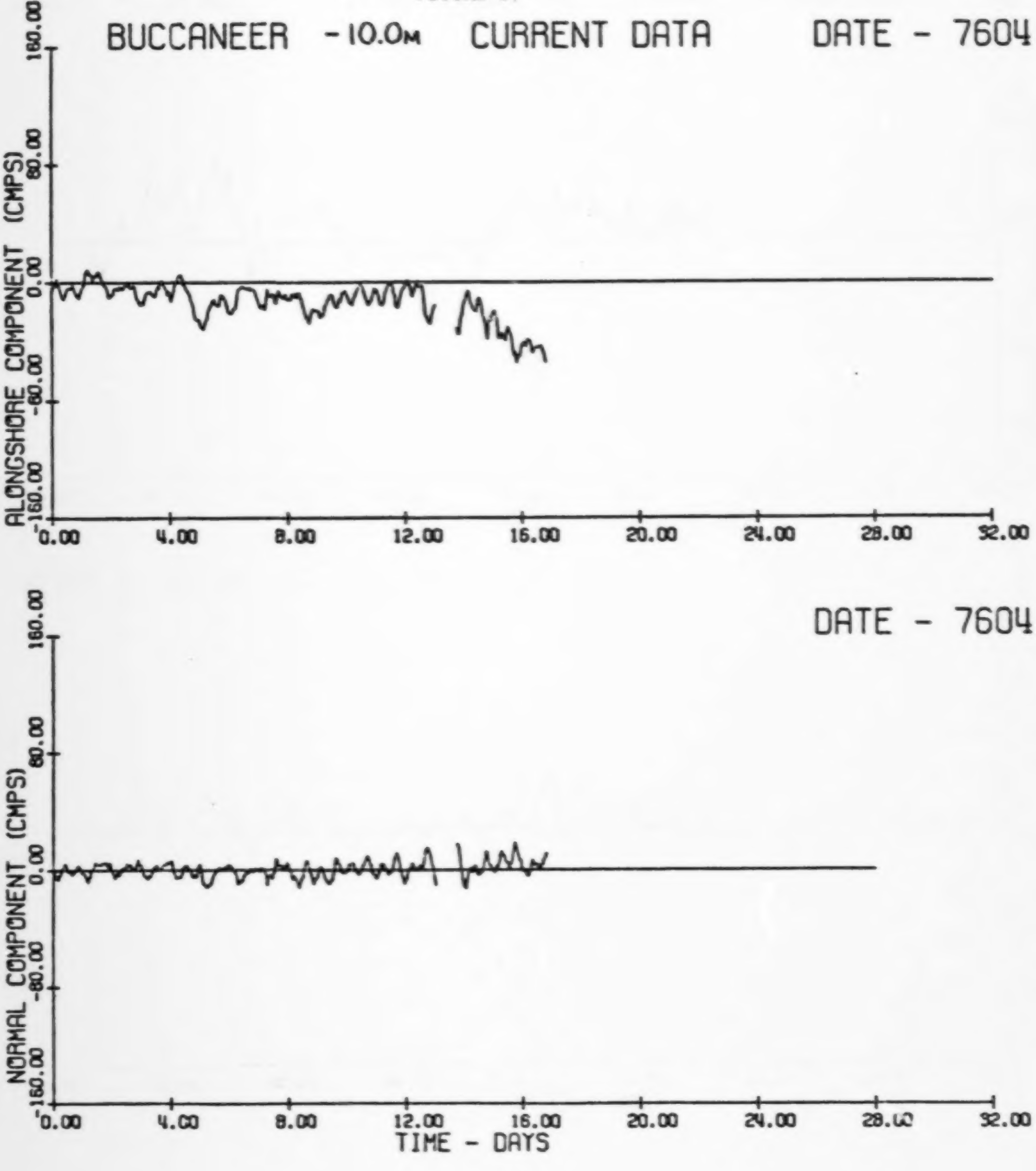

BUCCANEER -10.0M CURRENT DATA
DATE - 7604
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7604
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 28

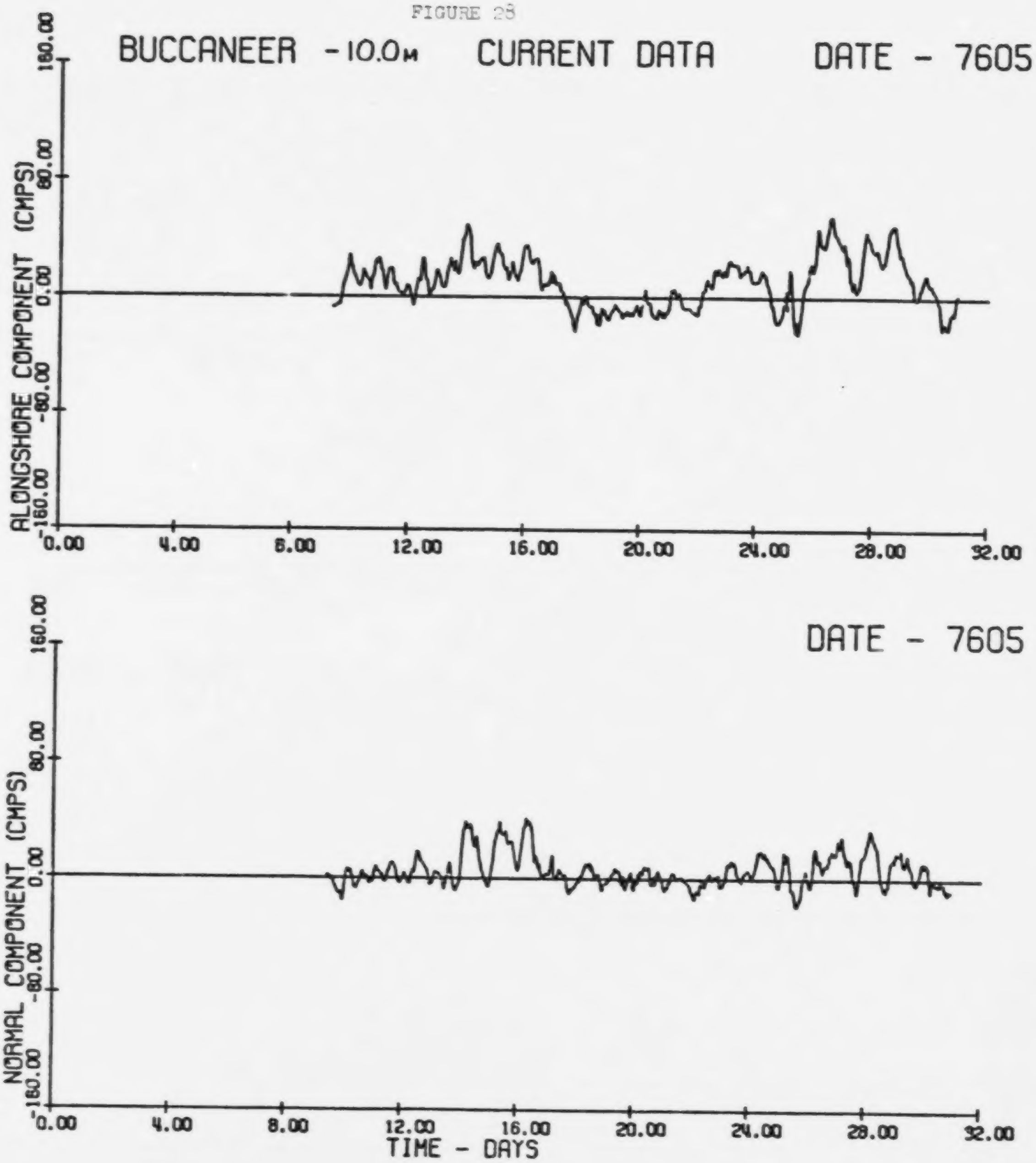

BUCCANEER -10.0M CURRENT DATA
DATE - 7605
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7605
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 29

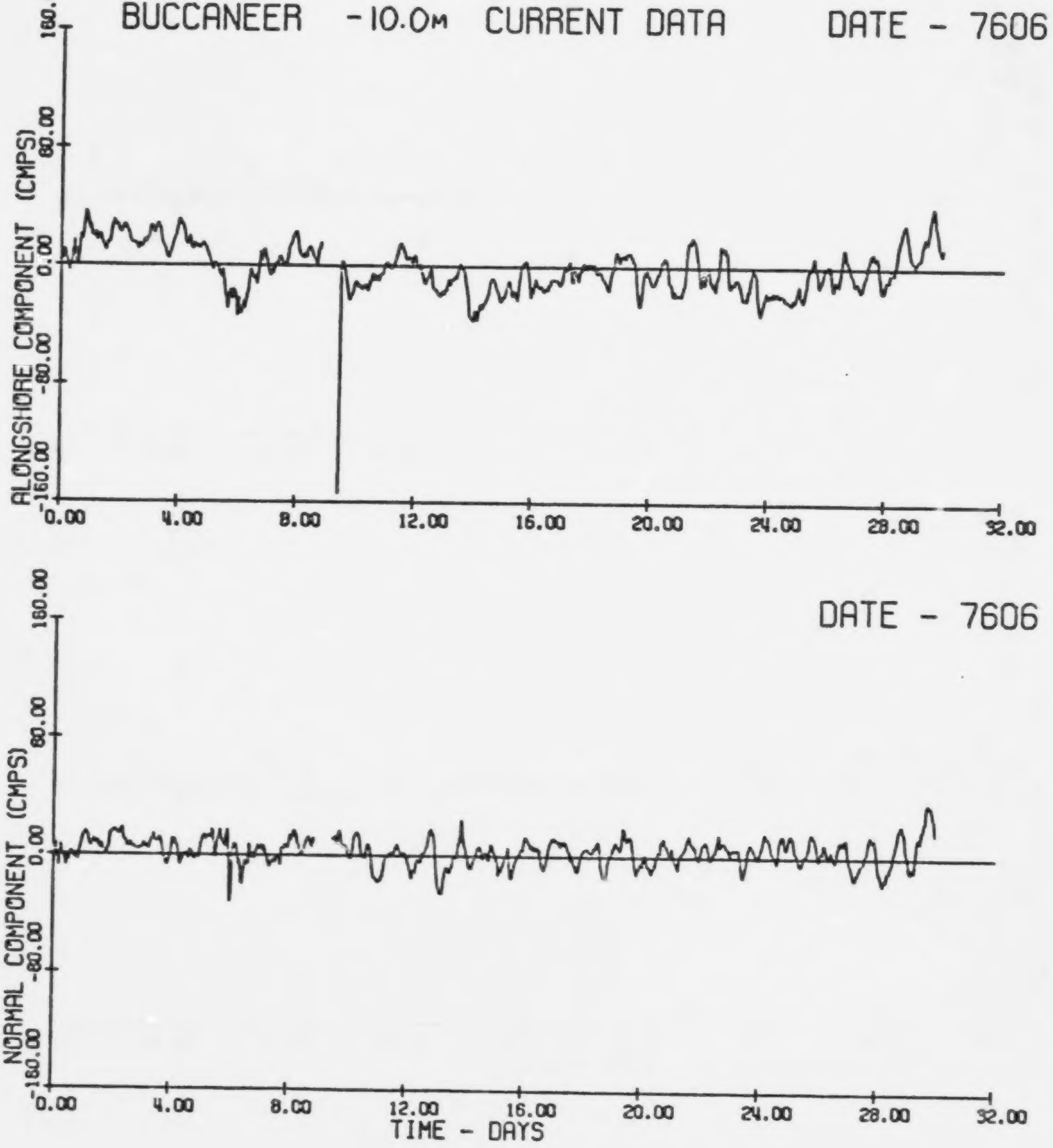

BUCCANEER -10.0M CURRENT DATA
DATE - 7606
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7606
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 30

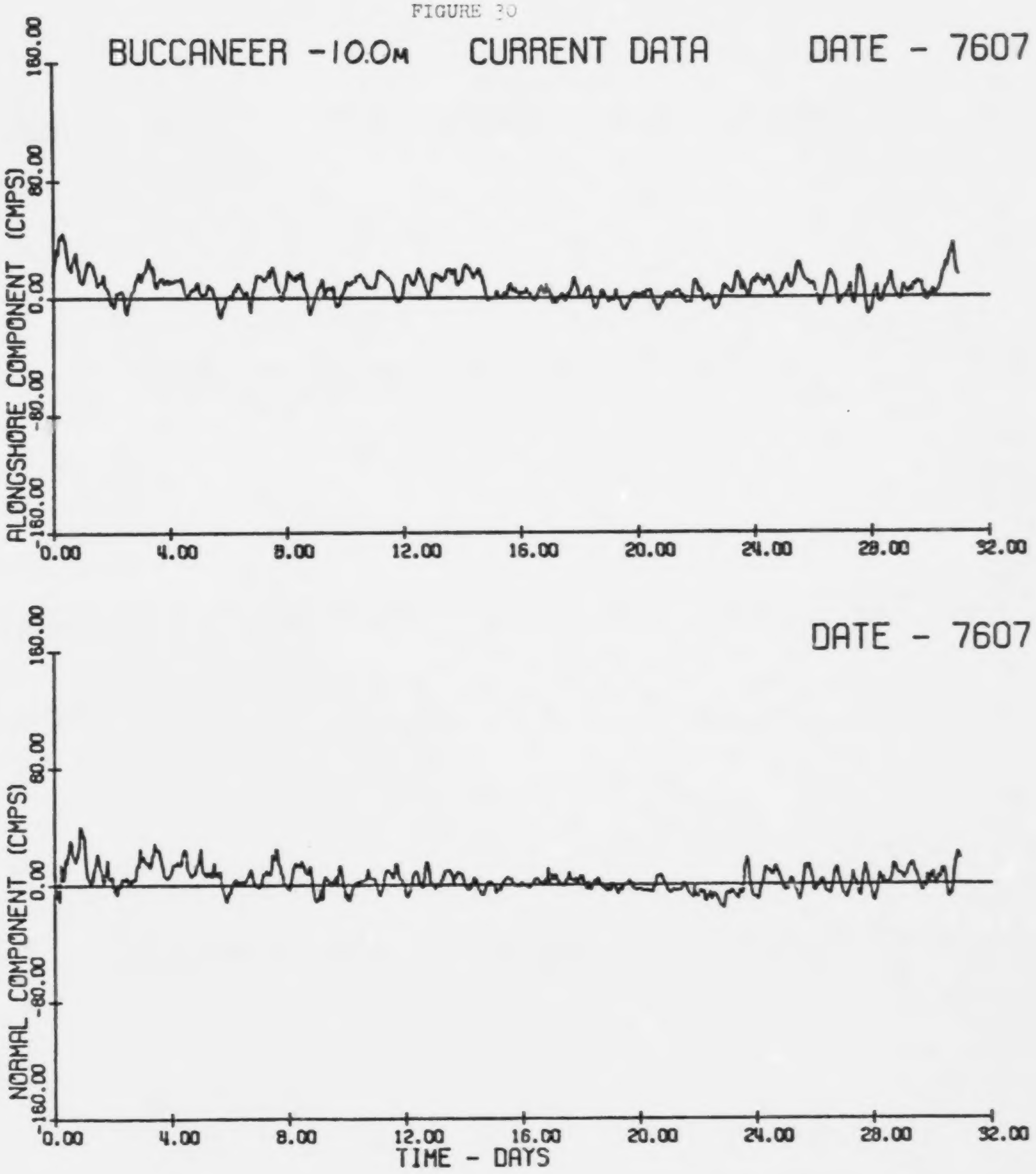

BUCCANEER -10.0M CURRENT DATA DATE - 7607
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7607
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 31

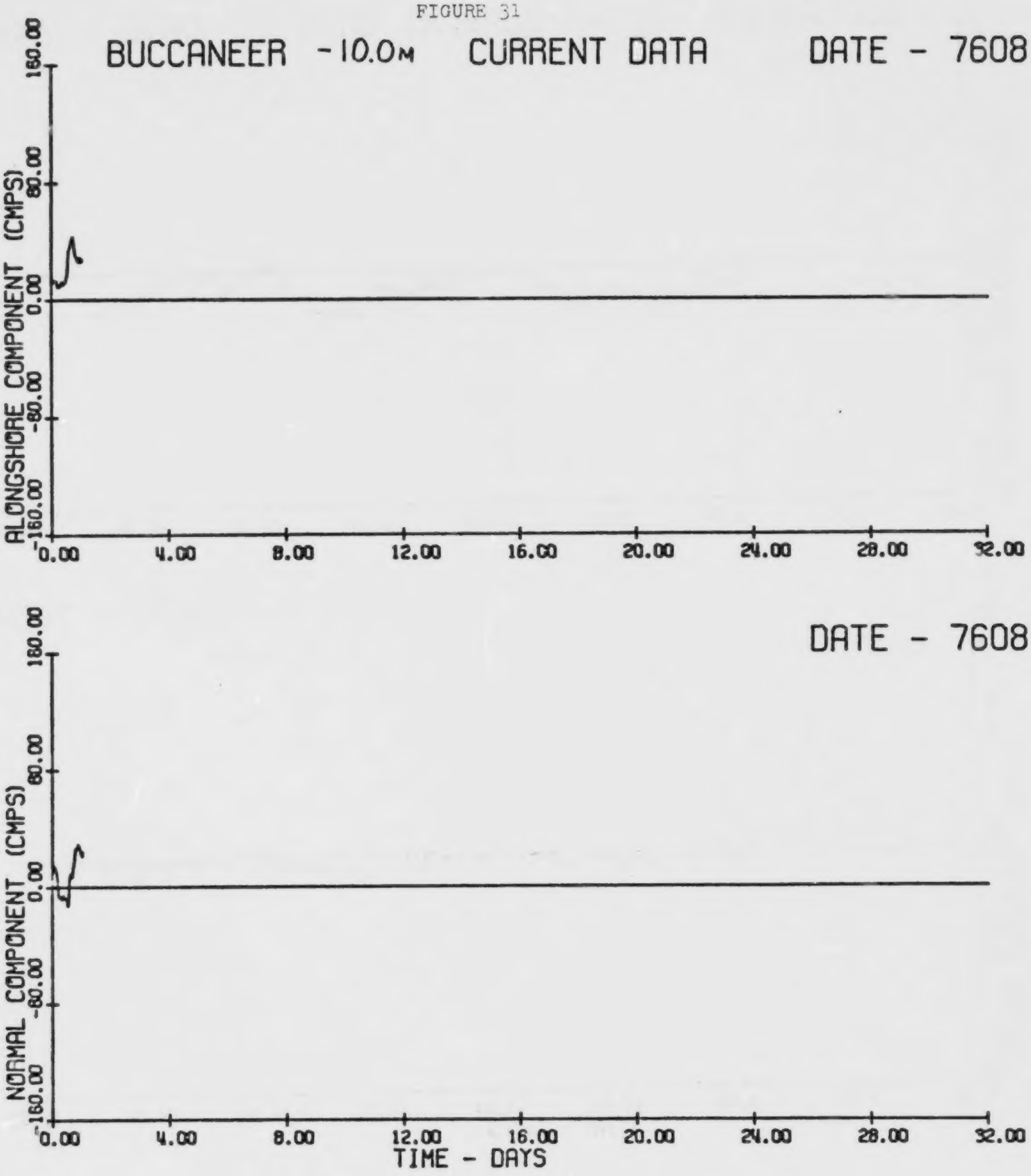

BUCCANEER -10.0M CURRENT DATA
DATE - 7608
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7608
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 32

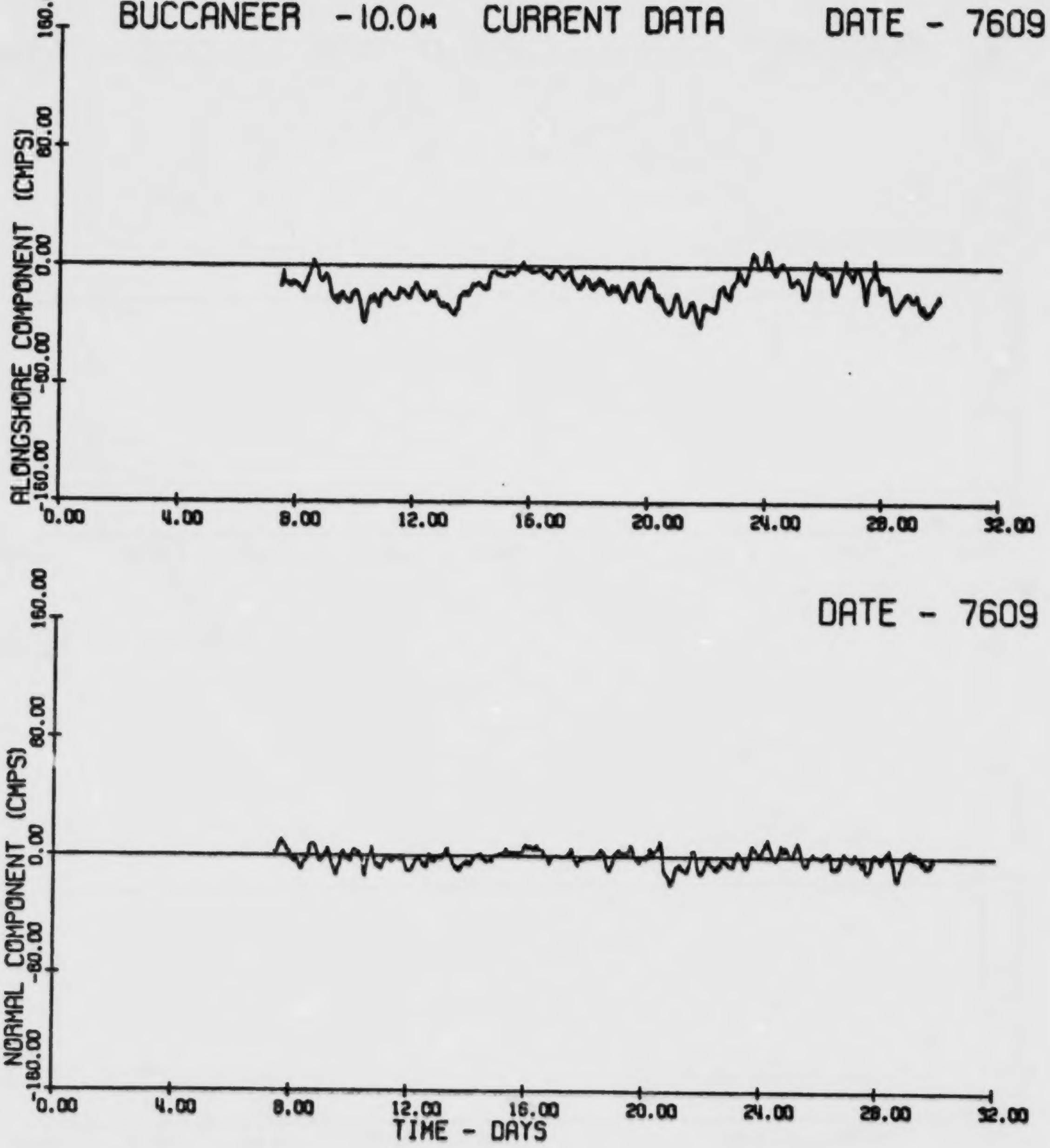

BUCCANEER -10.0M CURRENT DATA
DATE - 7609
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7609
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 33

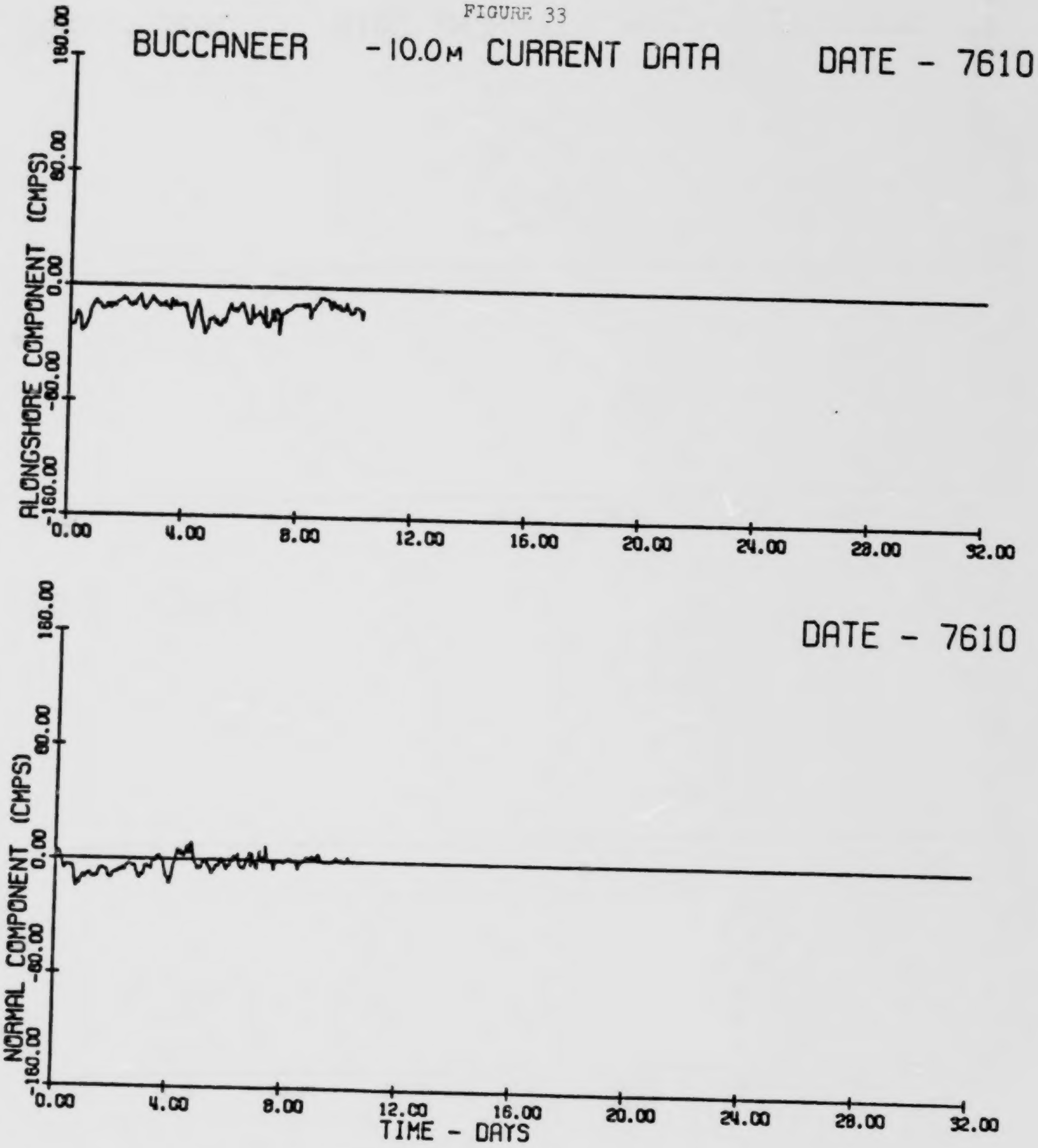

BUCCANEER -10.0M CURRENT DATA
DATE - 7610
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7610
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 34

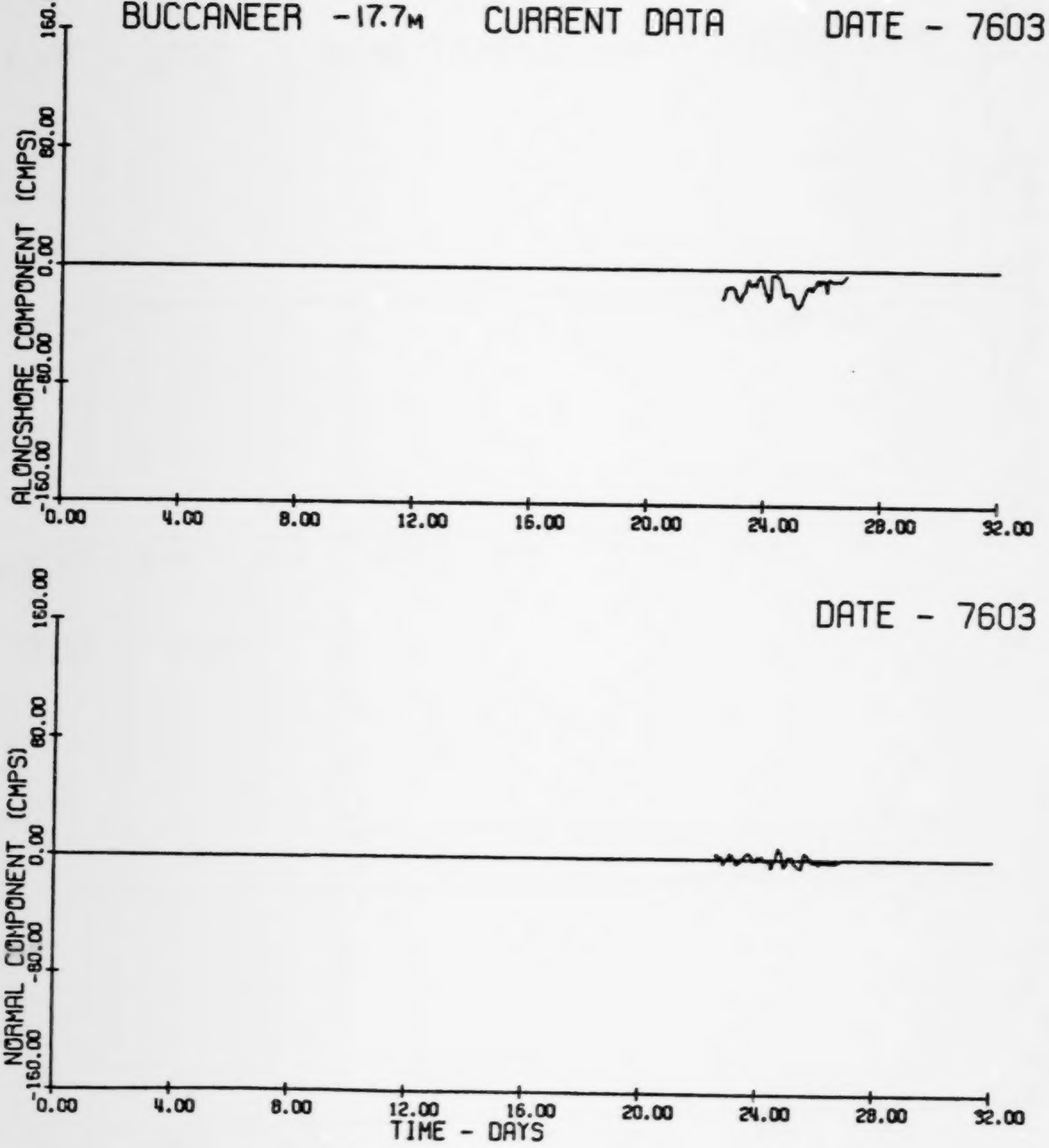

BUCCANEER -17.7M CURRENT DATA
DATE - 7603
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7603
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 35

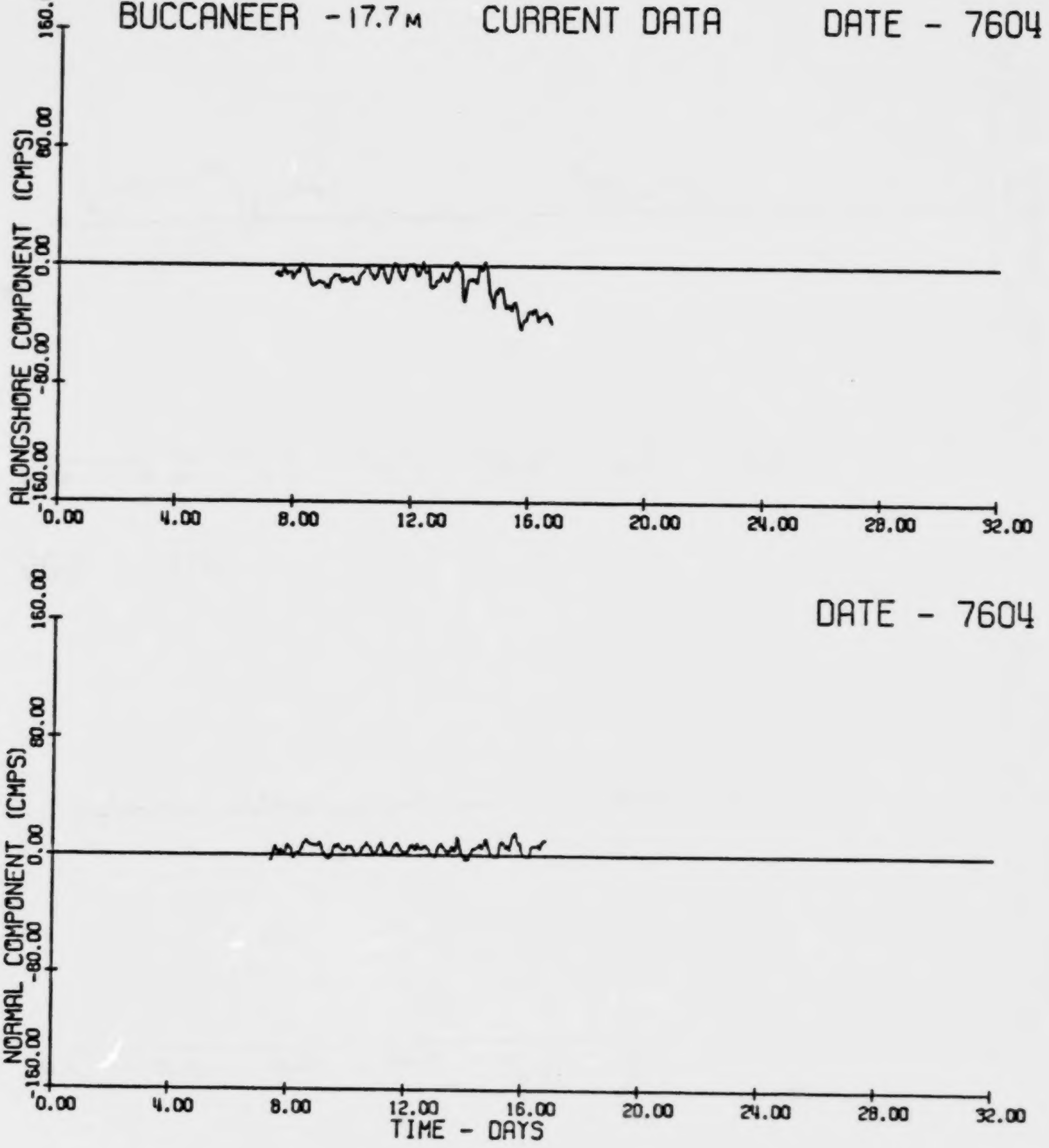

BUCCANEER -17.7 M CURRENT DATA DATE - 7604
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7604
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 36

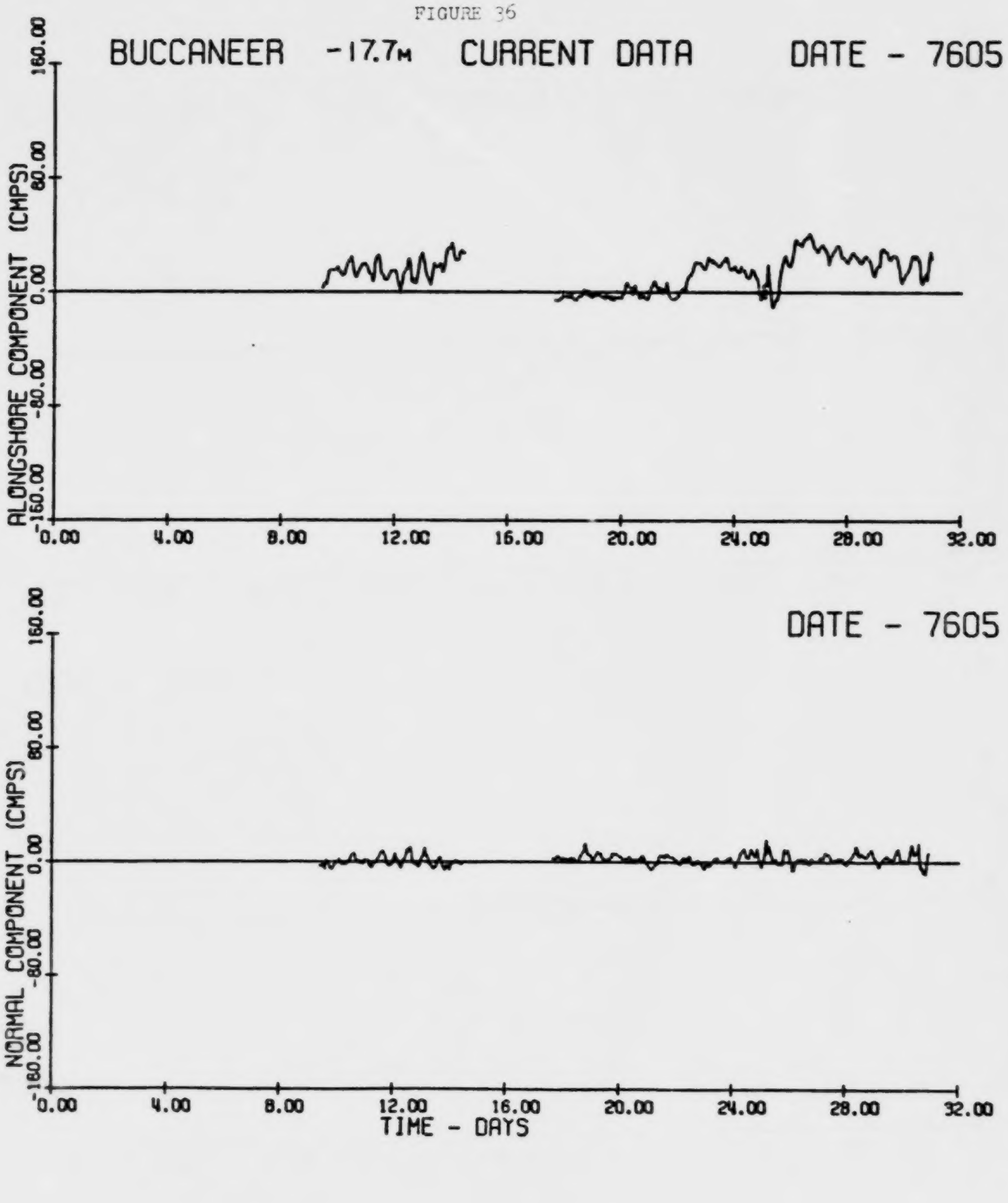

BUCCANEER -17.7M CURRENT DATA DATE - 7605
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7605
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 37

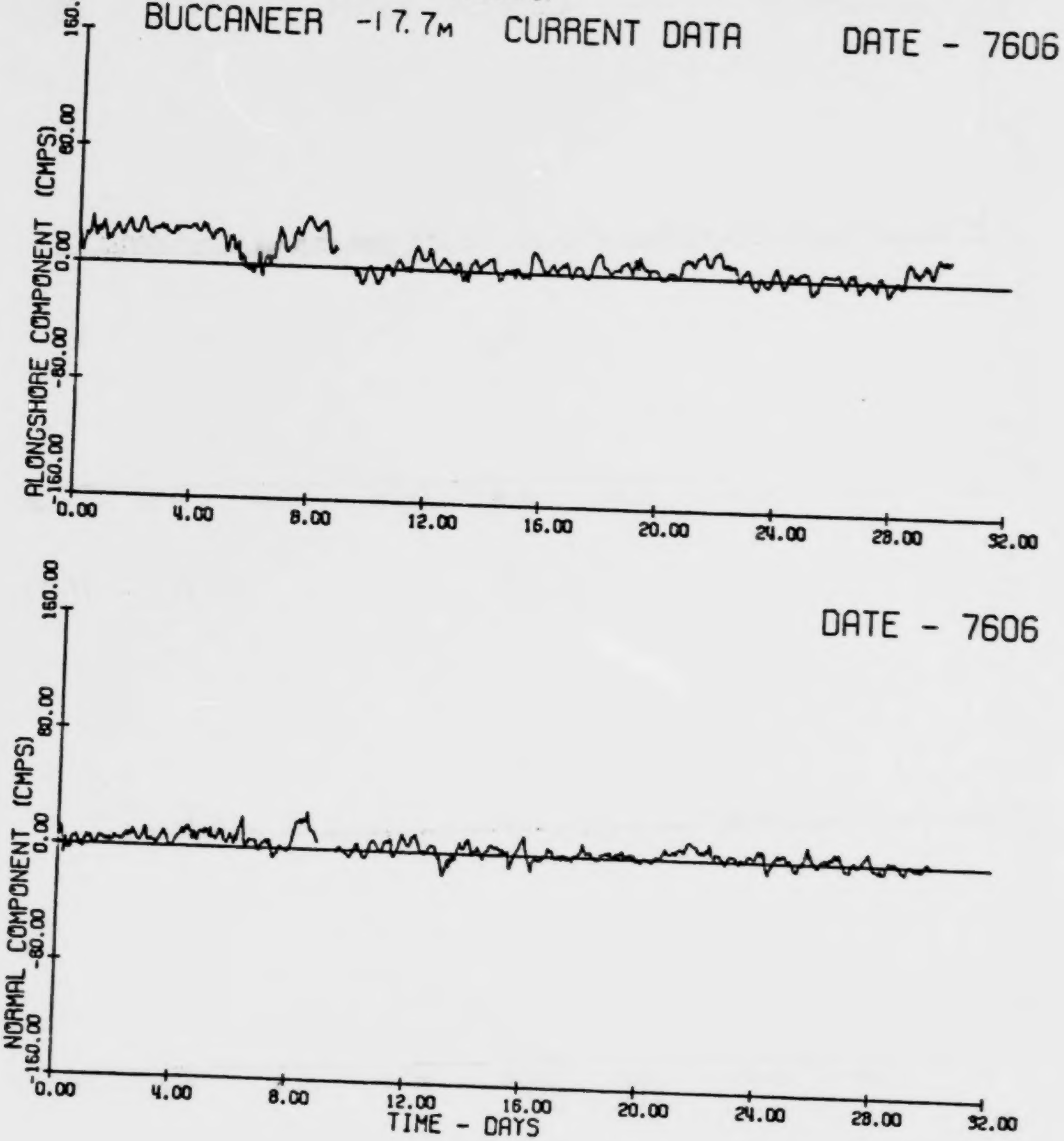

BUCCANEER -17.7M CURRENT DATA
DATE - 7606
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7606
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 38

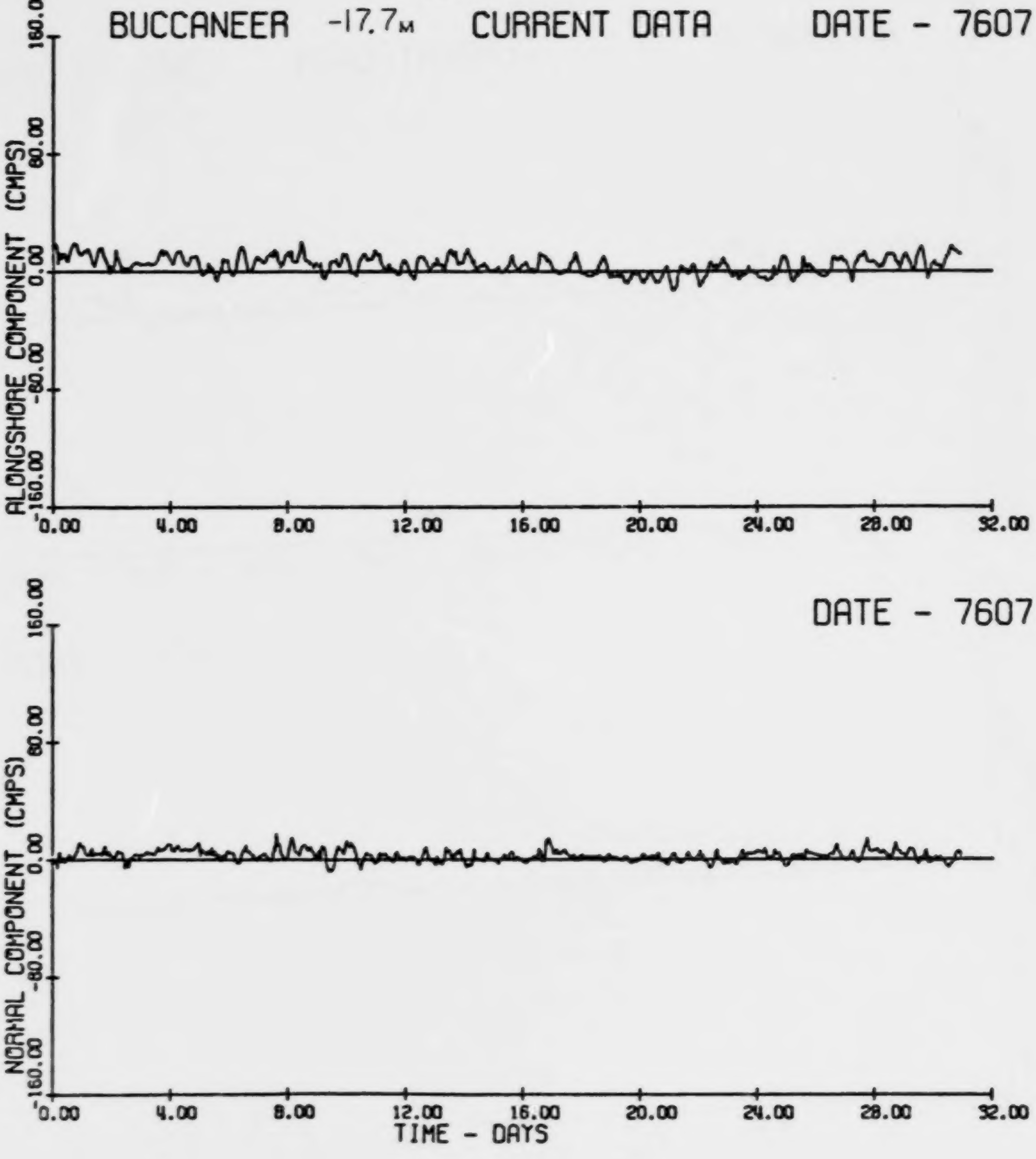

BUCCANEER -17.7M CURRENT DATA DATE - 7607
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7607
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 39

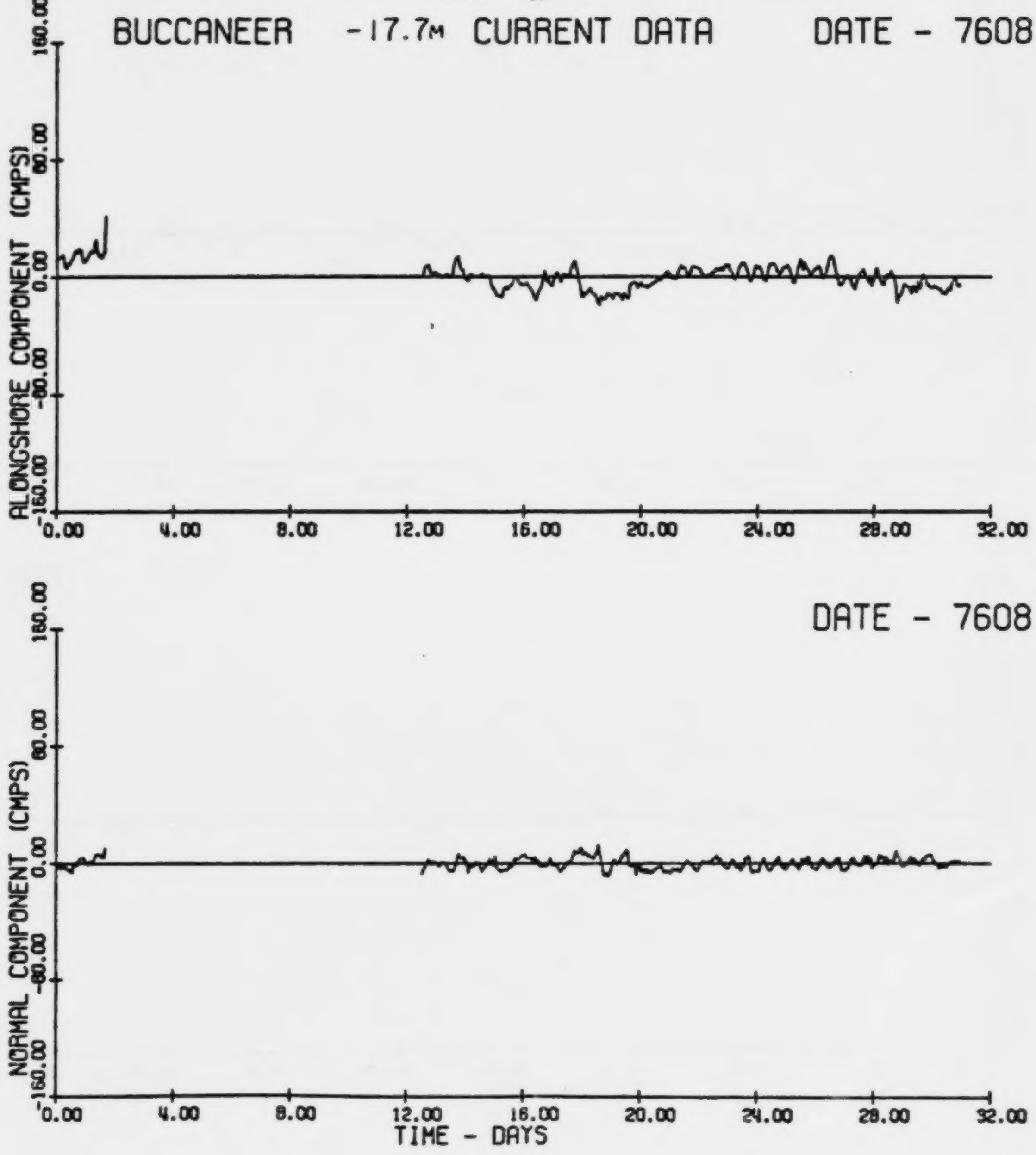

BUCCANEER -17.7M CURRENT DATA DATE - 7608
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7608
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 40

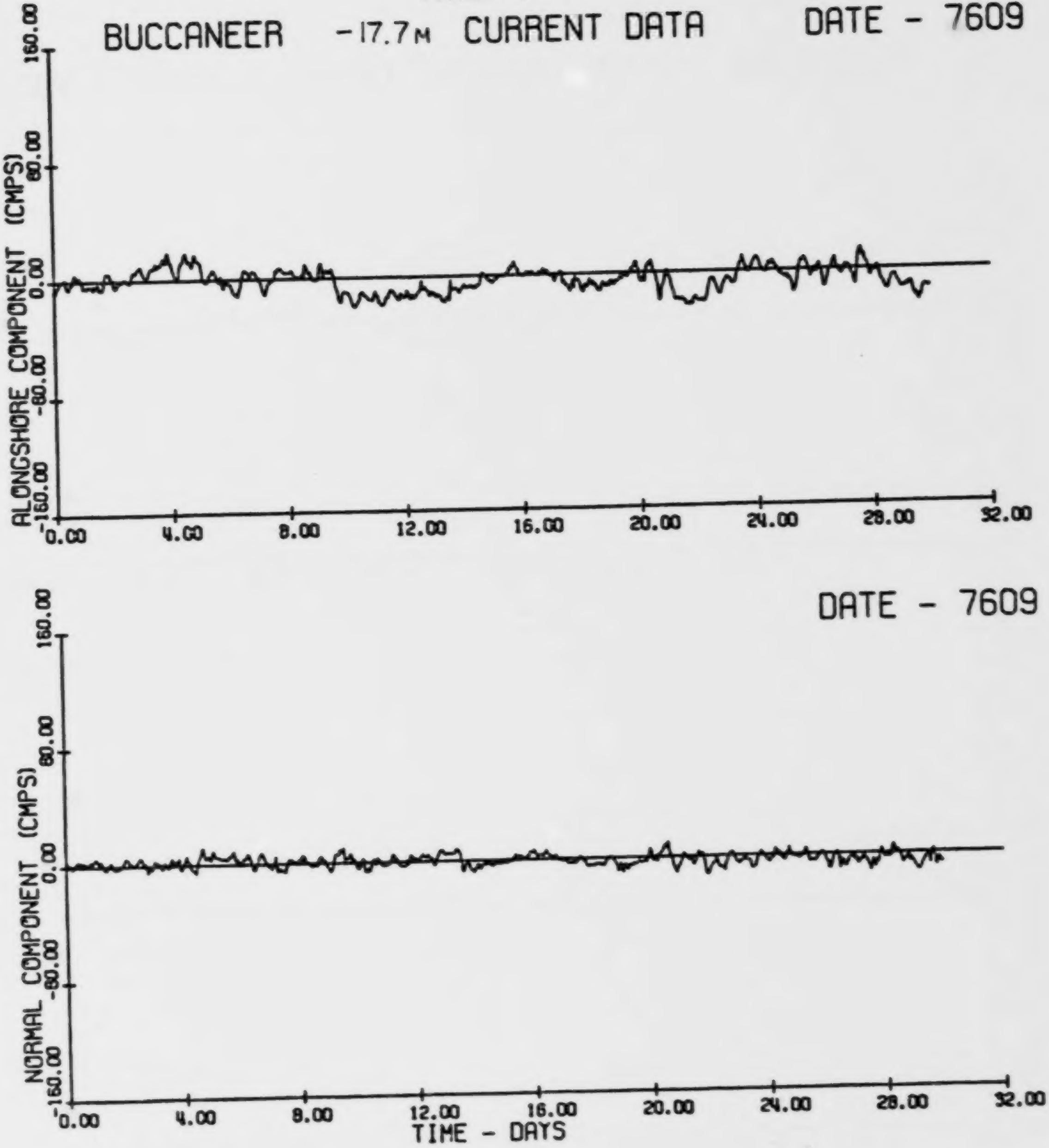
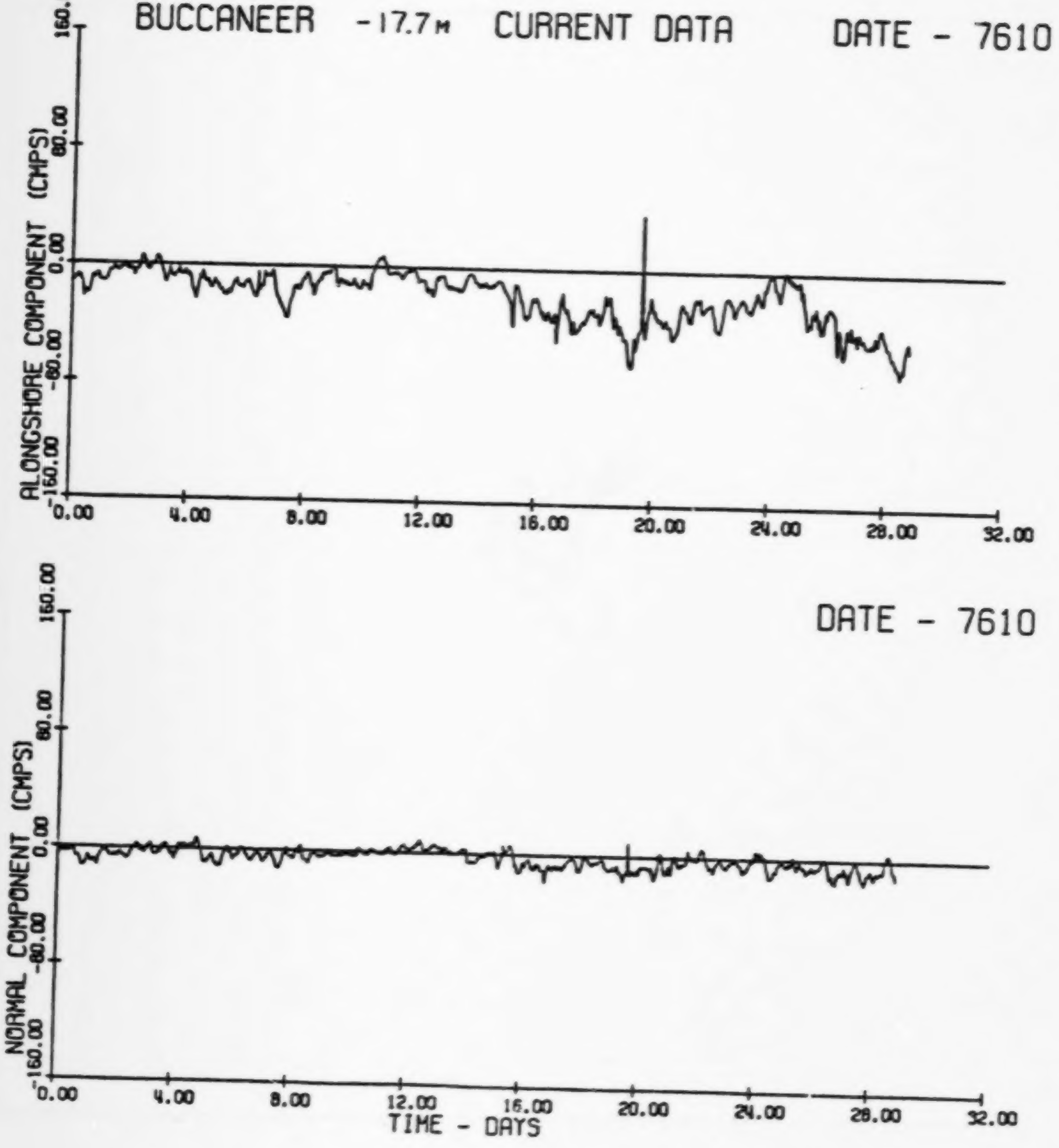

BUCCANEER -17.7M CURRENT DATA
DATE - 7609
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7609
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

FIGURE 41


BUCCANEER -17.7M CURRENT DATA
DATE - 7610
ALONGSHORE COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DATE - 7610
NORMAL COMPONENT (CMPS)
160.00
80.00
0.00
-80.00
-160.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
TIME - DAYS

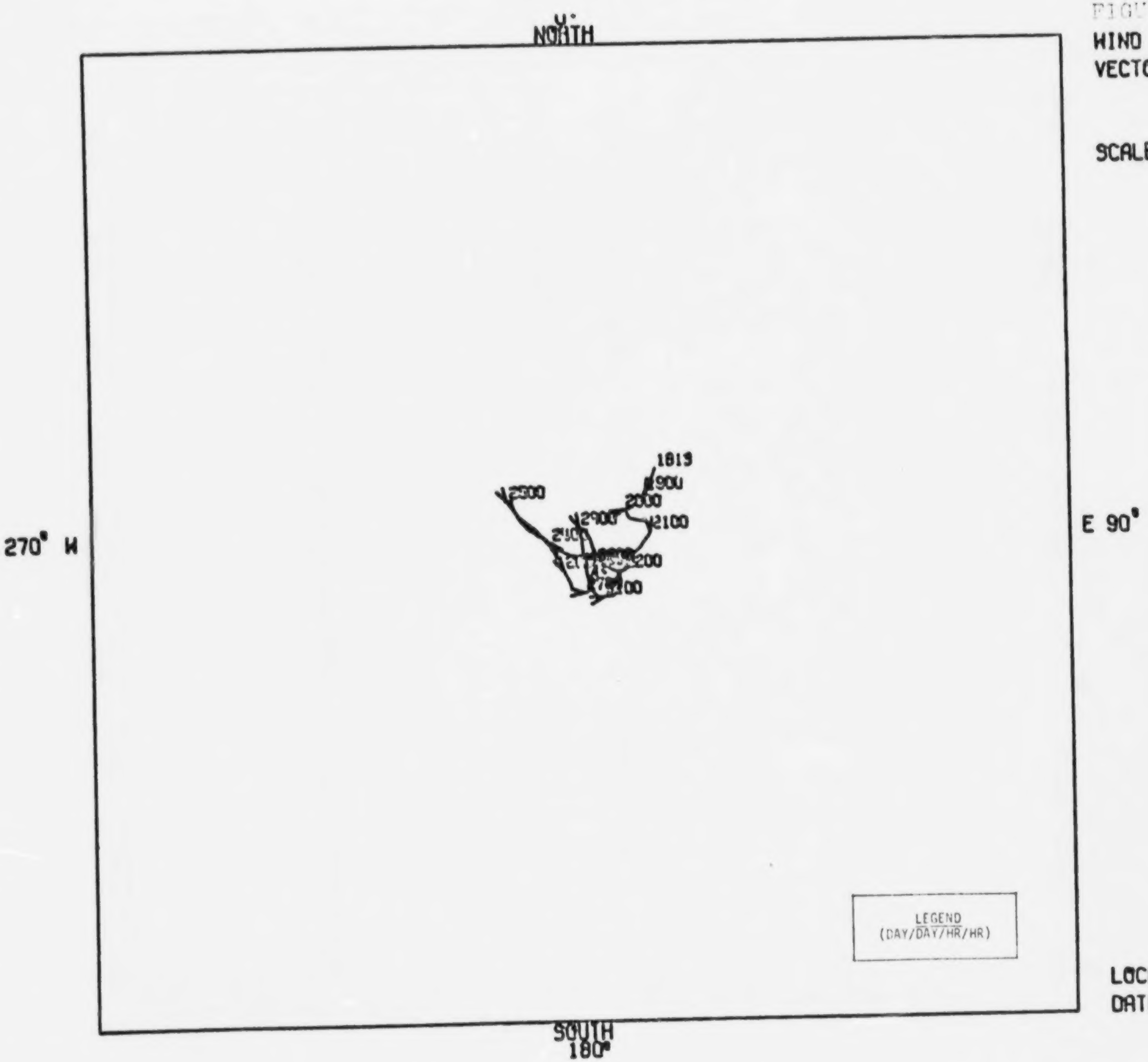


FIGURE [illegible]
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE 1 IN = 1717.80 KM

LOCATION - BUCCANEER
DATE - 7512

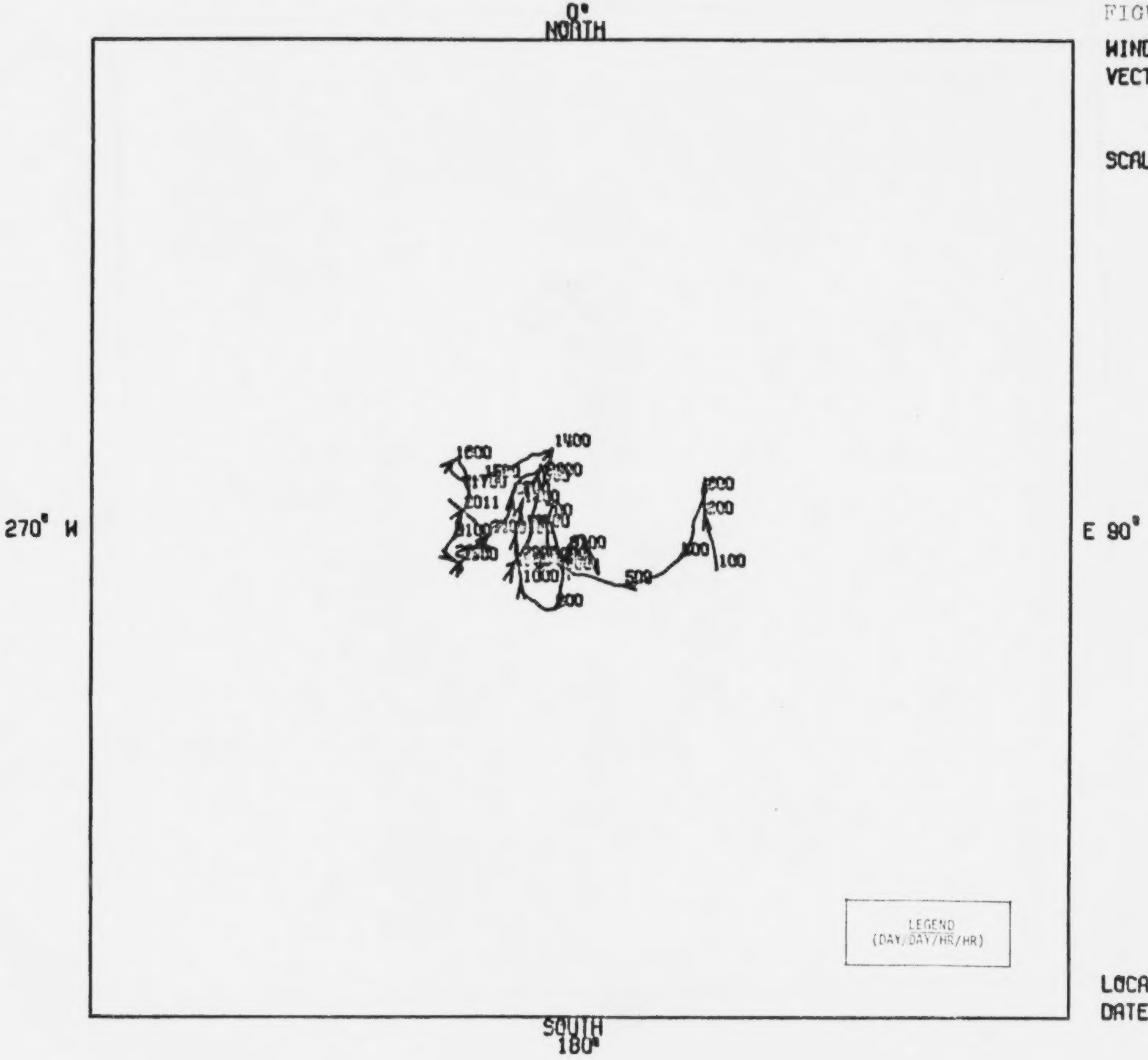


FIGURE 43

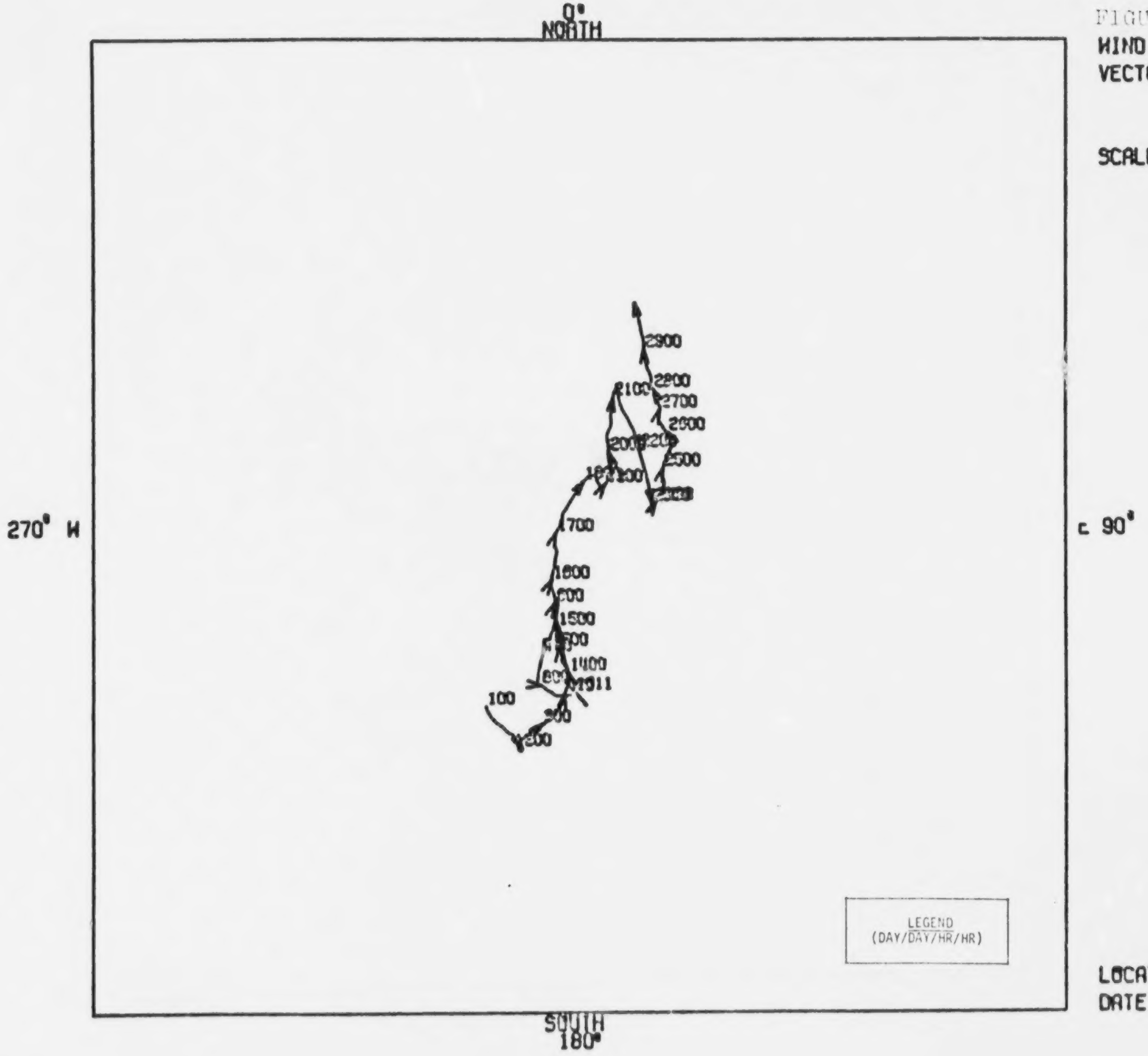
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 KM

LOCATION - BUCCANEER
DATE - 7601

FIGURE 44
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 K



LOCATION - BUCCANEER
DATE - 7602

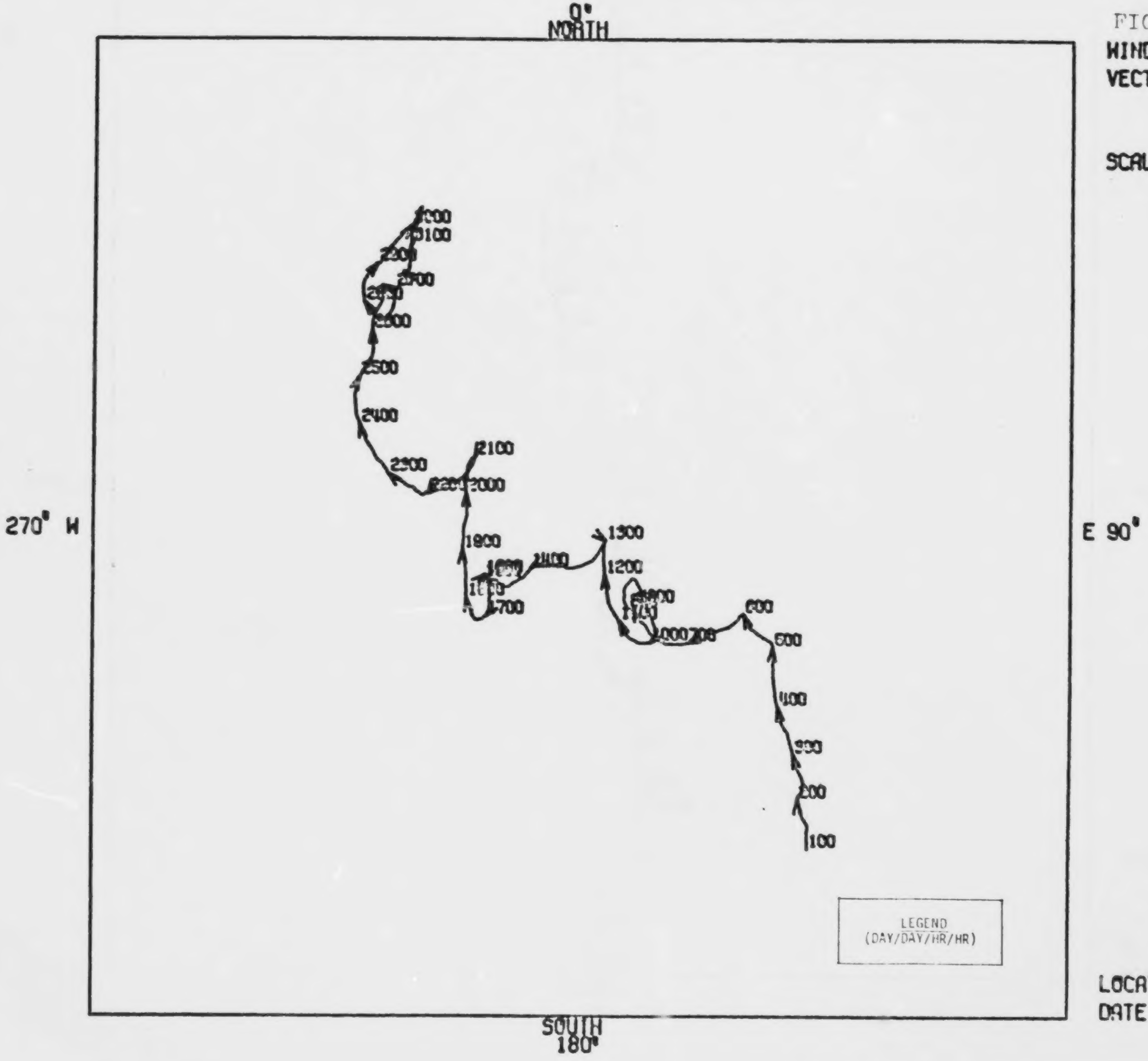


FIGURE 45
**WIND PROGRESSIVE
VECTOR DIAGRAM**

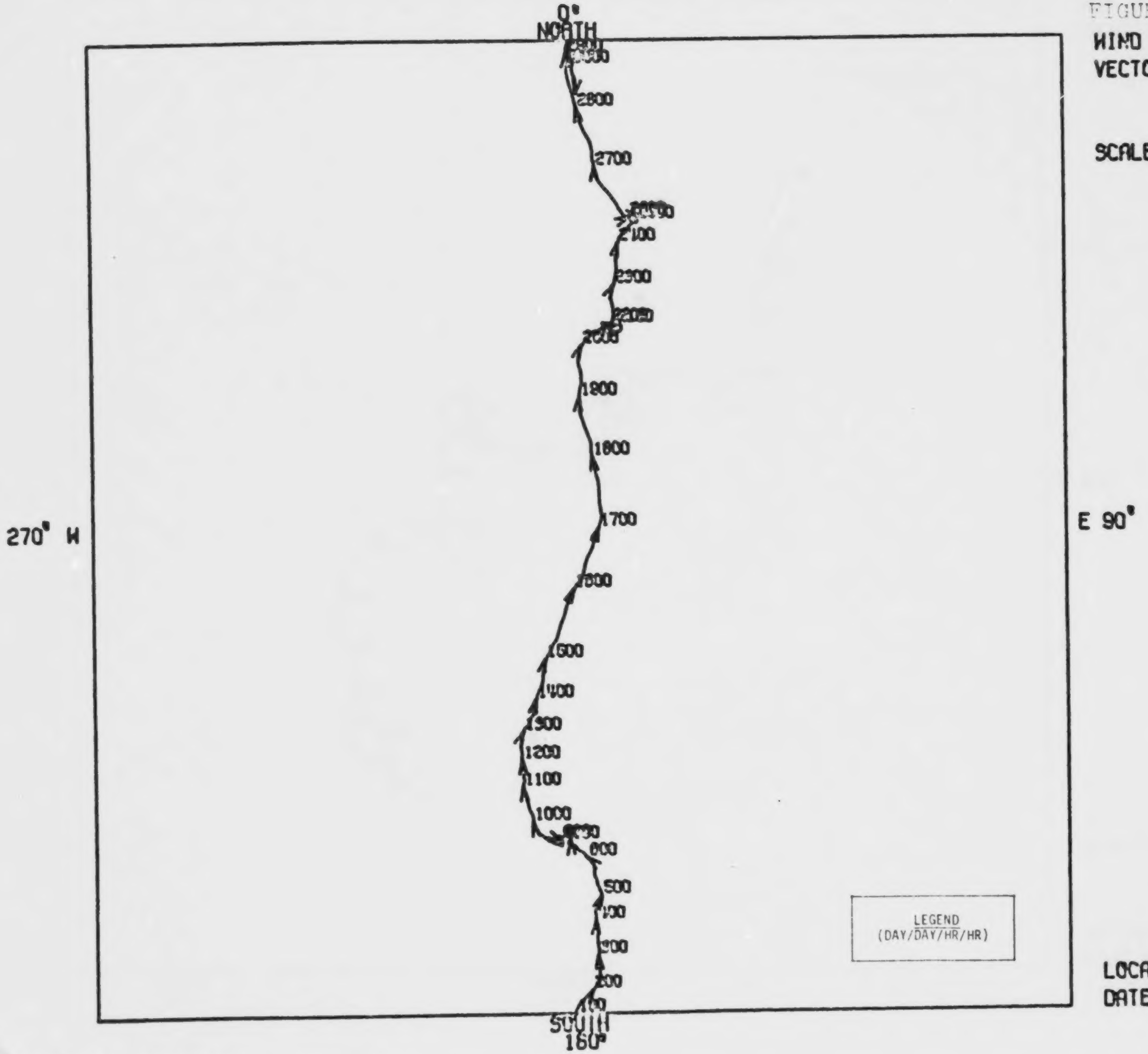
SCALE - 1 IN = 1717.80 KM

**LOCATION - BUCCANEER
DATE - 7603**

FIGURE 46

WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 KM



LOCATION - BUCCANEER
DATE - 7604

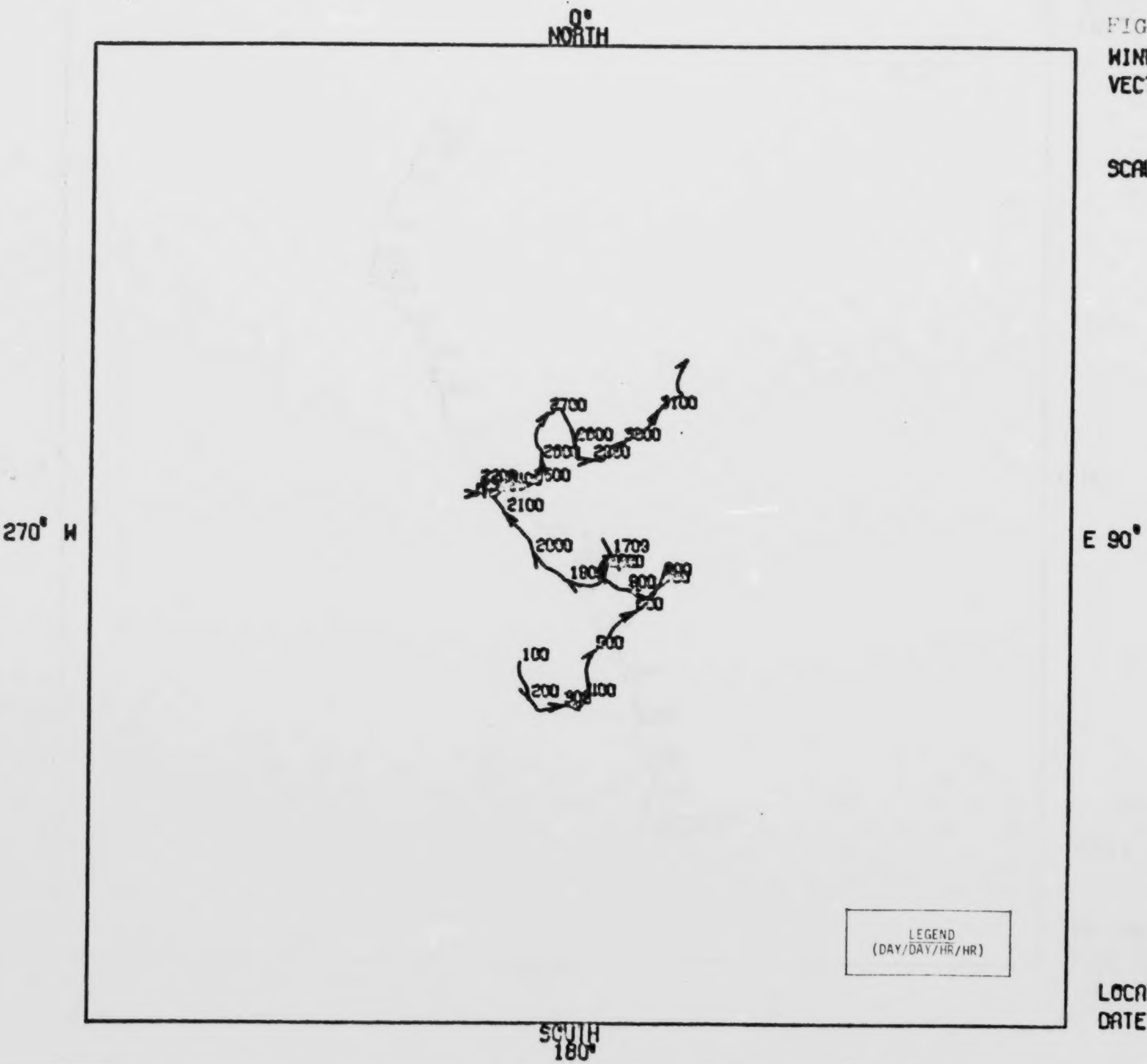


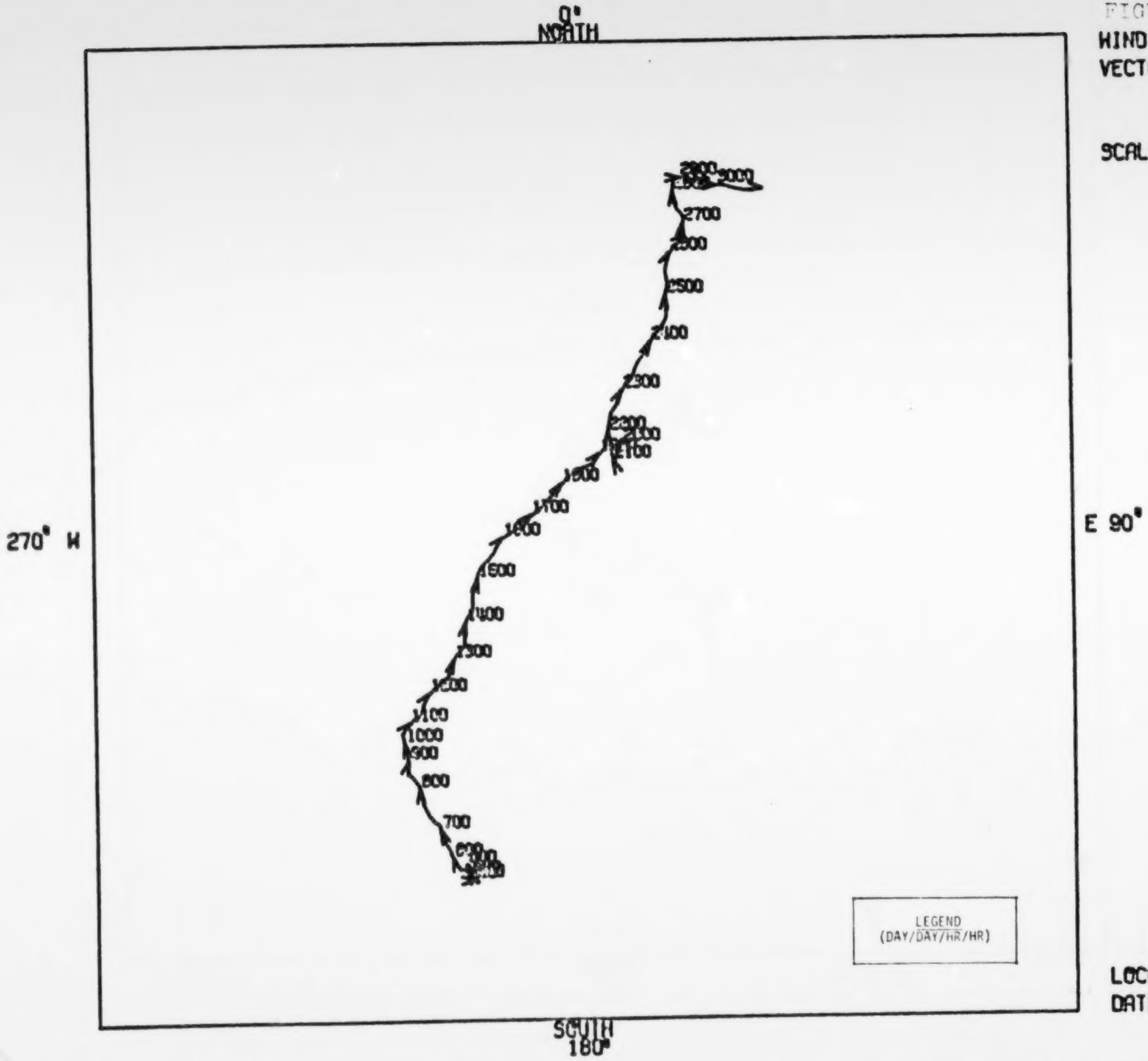
FIGURE 47
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 |

LOCATION - BUCCANEER
DATE - 7605

FIGURE 48
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 KM



LOCATION - BUCCANEER
DATE - 7606

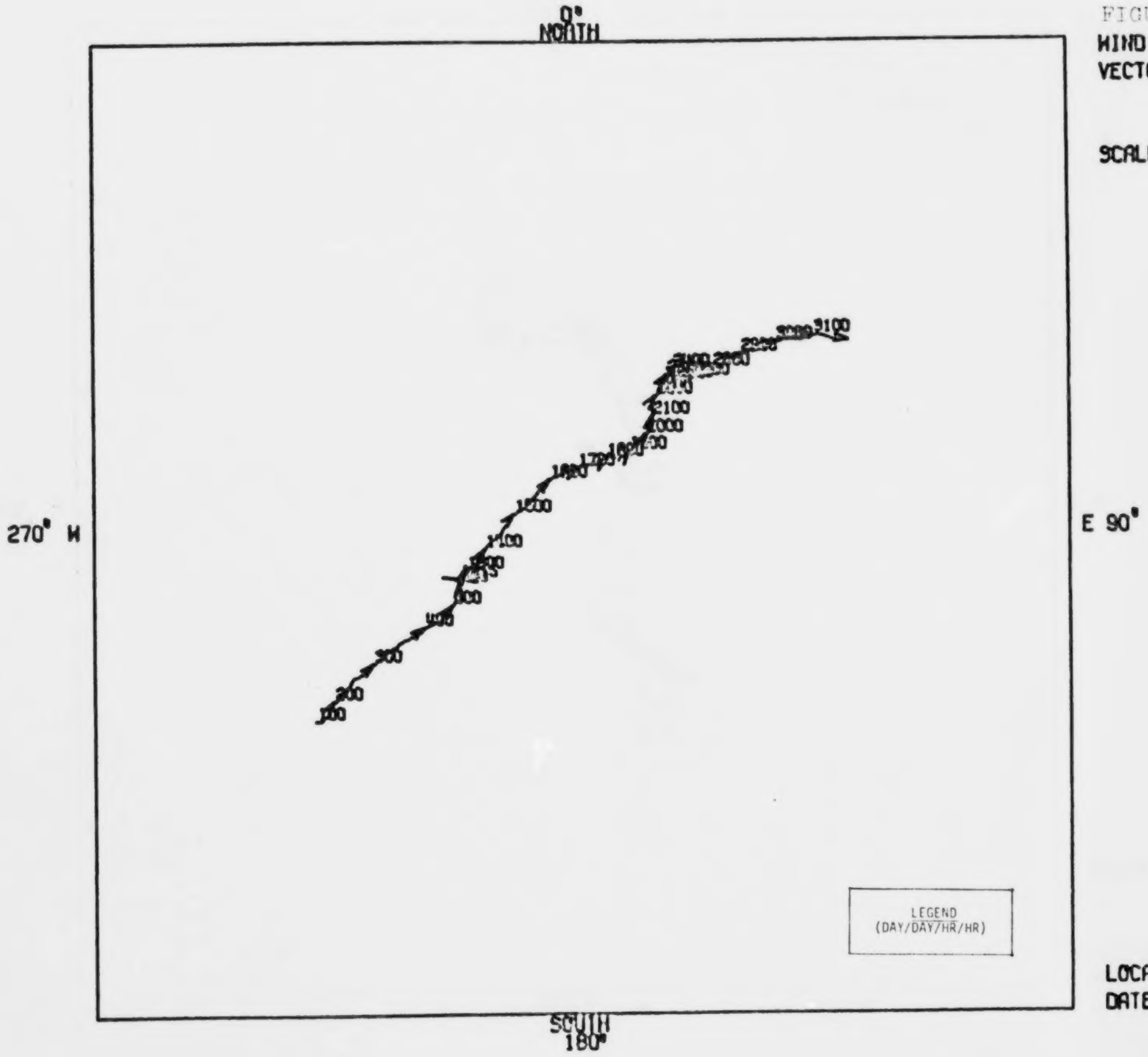


FIGURE 49
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 K

LOCATION - BUCCANEER
DATE - 7607

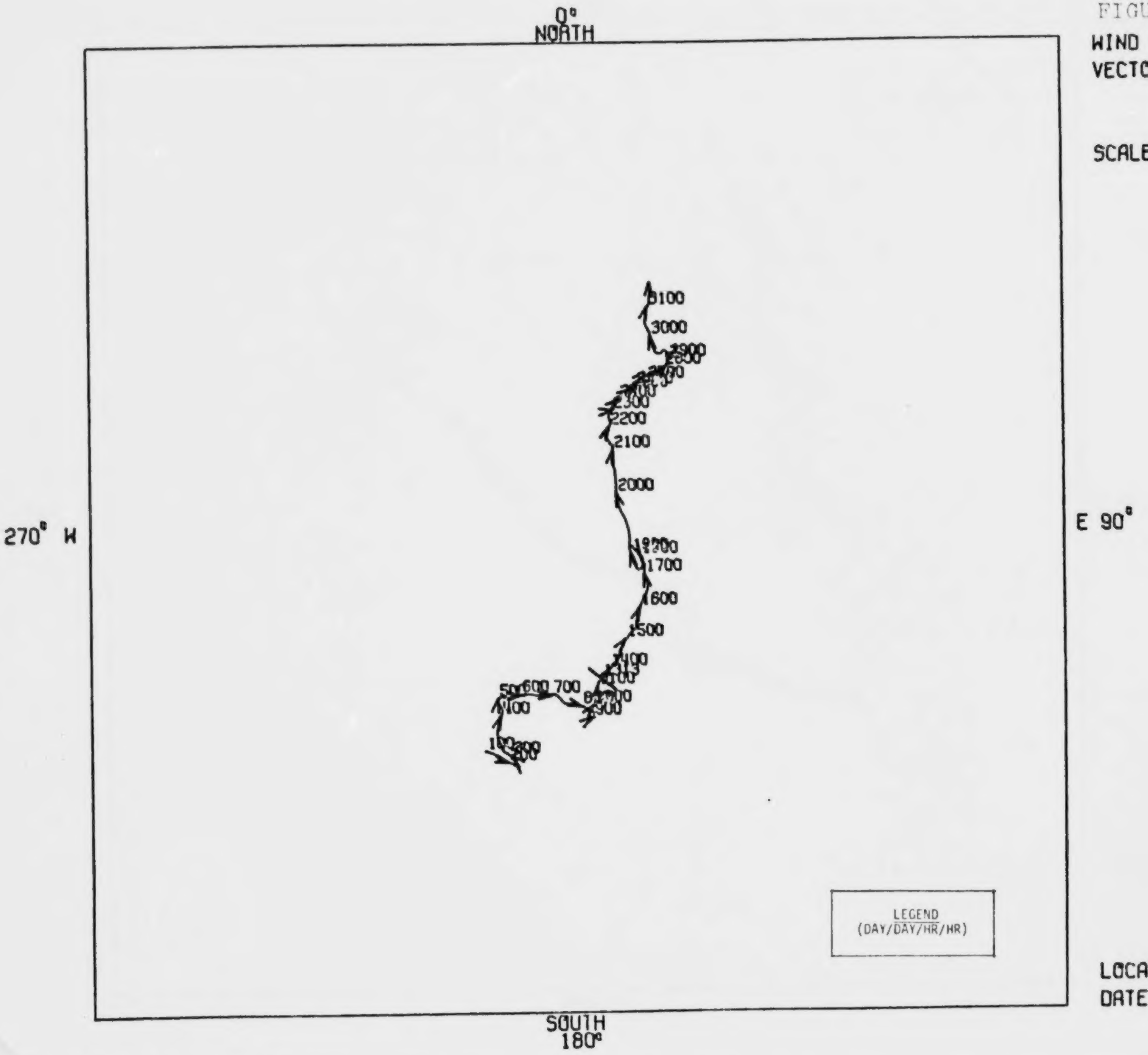


FIGURE 50
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 KM

LOCATION - BUCCANEER
DATE - 7608

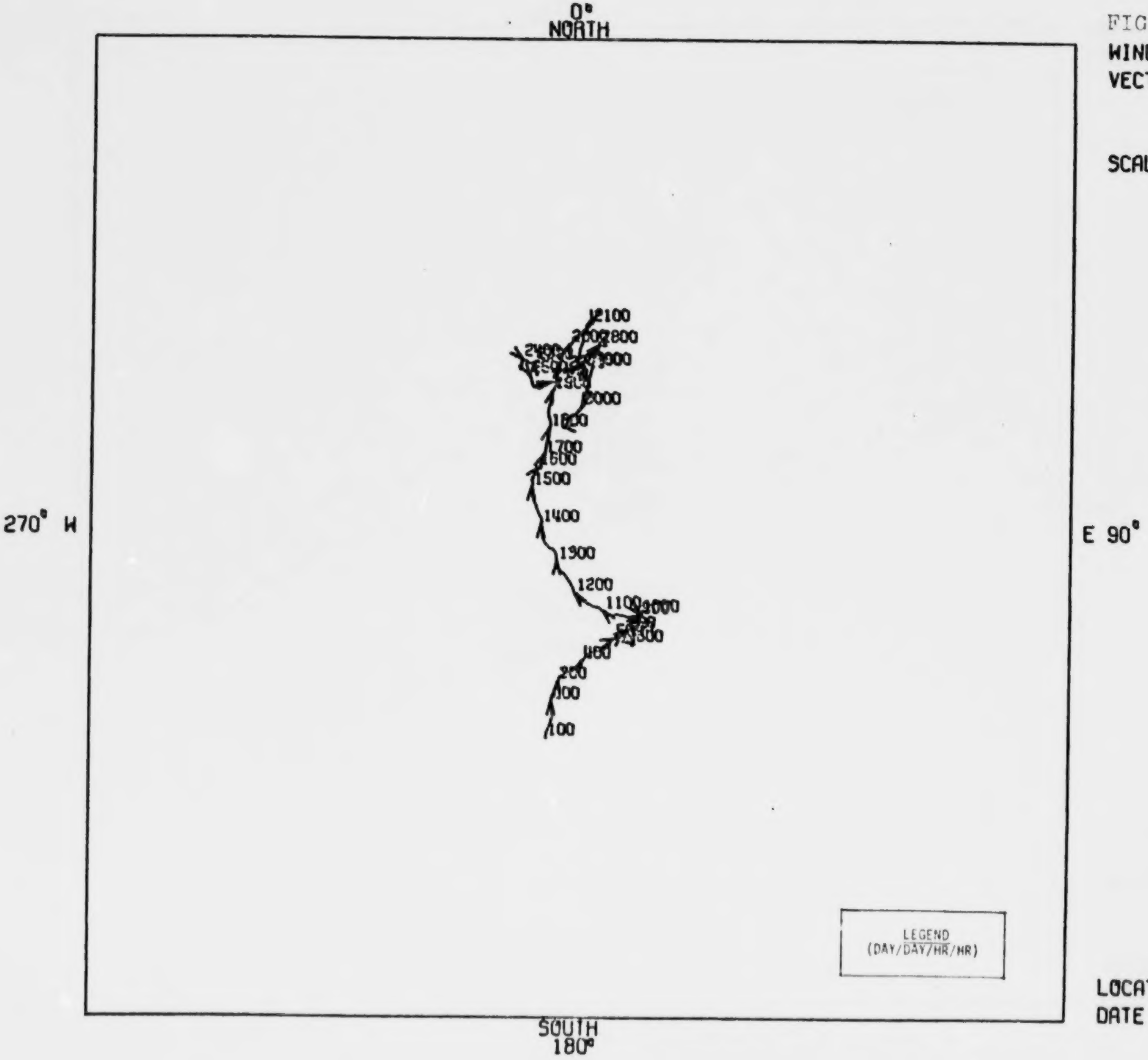


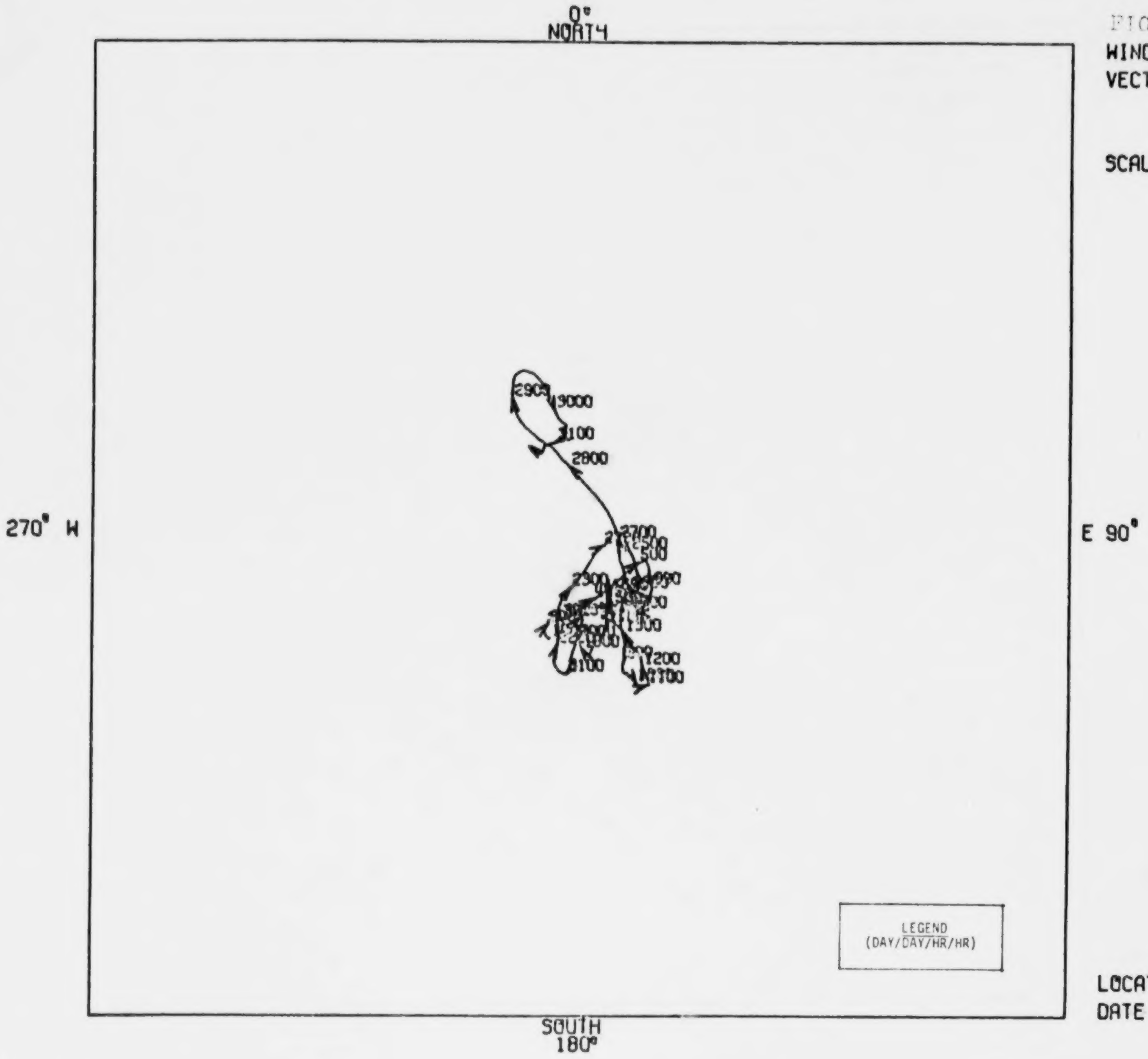
FIGURE 51
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 I

LOCATION - BUCCANEER
DATE - 7609

FIGURE 52
WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80 KM

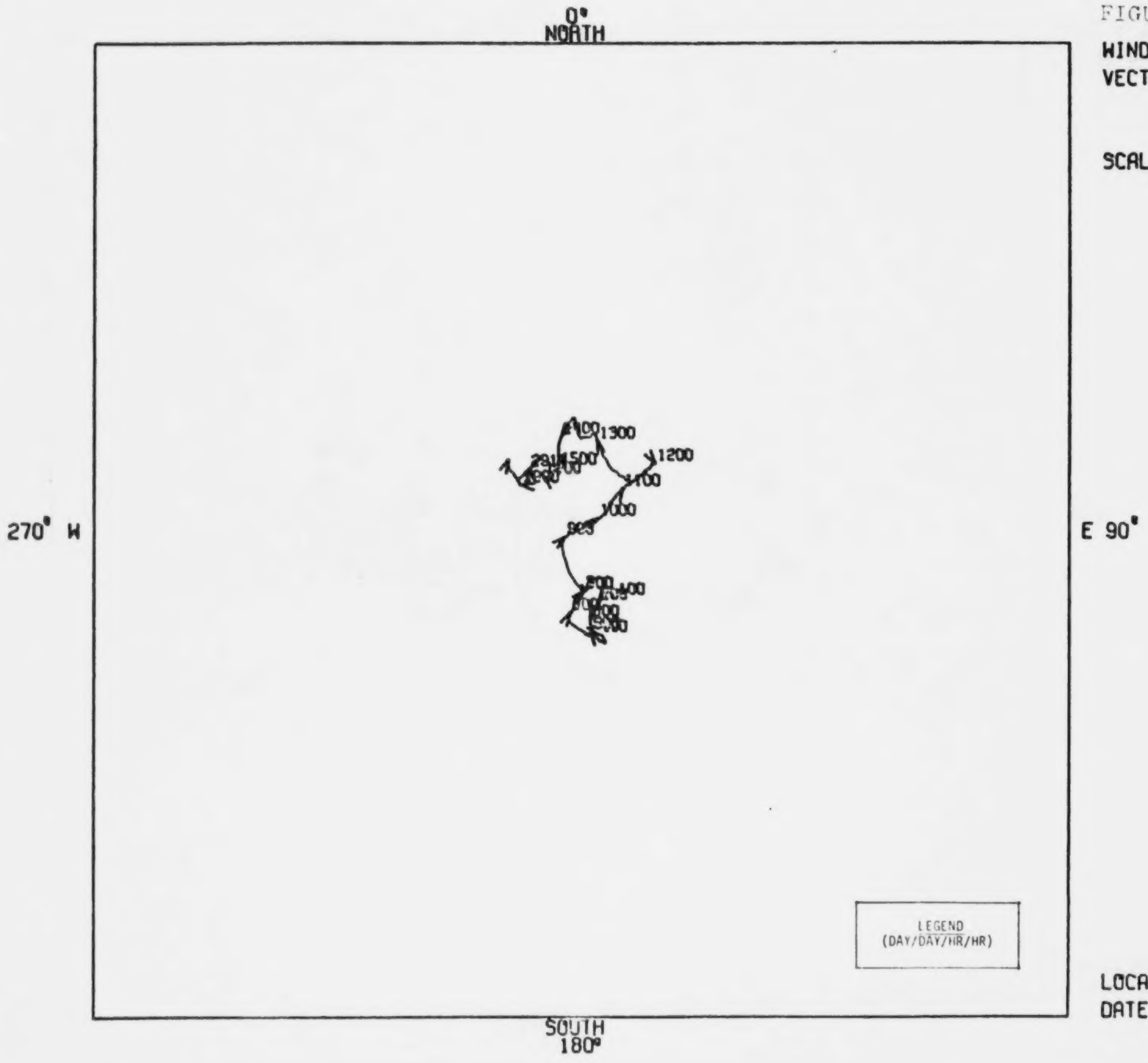


LOCATION - BUCCANEER
DATE - 7610

FIGURE 53

WIND PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 1717.80



LOCATION - BUCCANEER
DATE - 7611

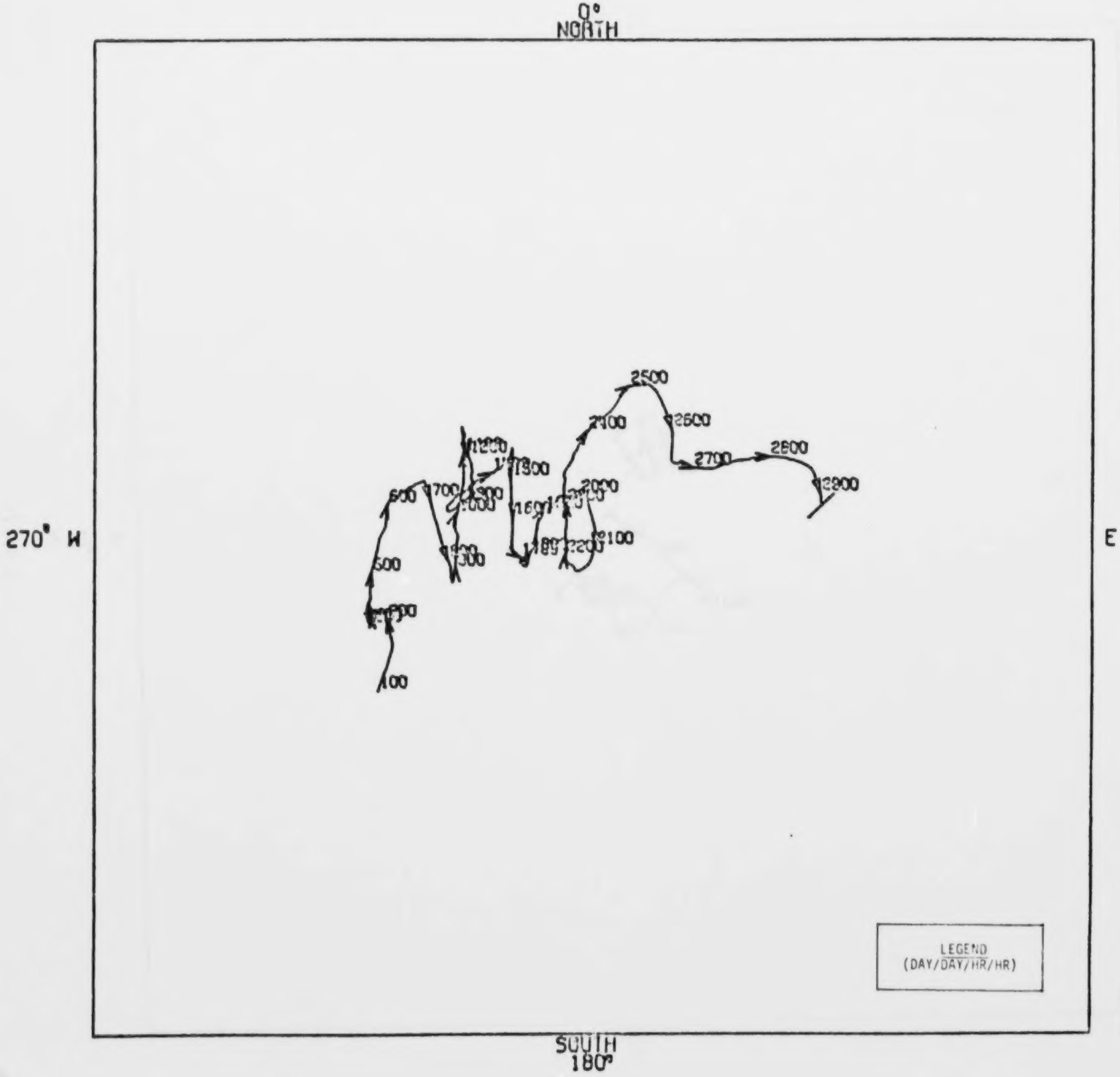


FIGURE 54
WIND PROGRESSIVE
VECTOR DIAGRAM

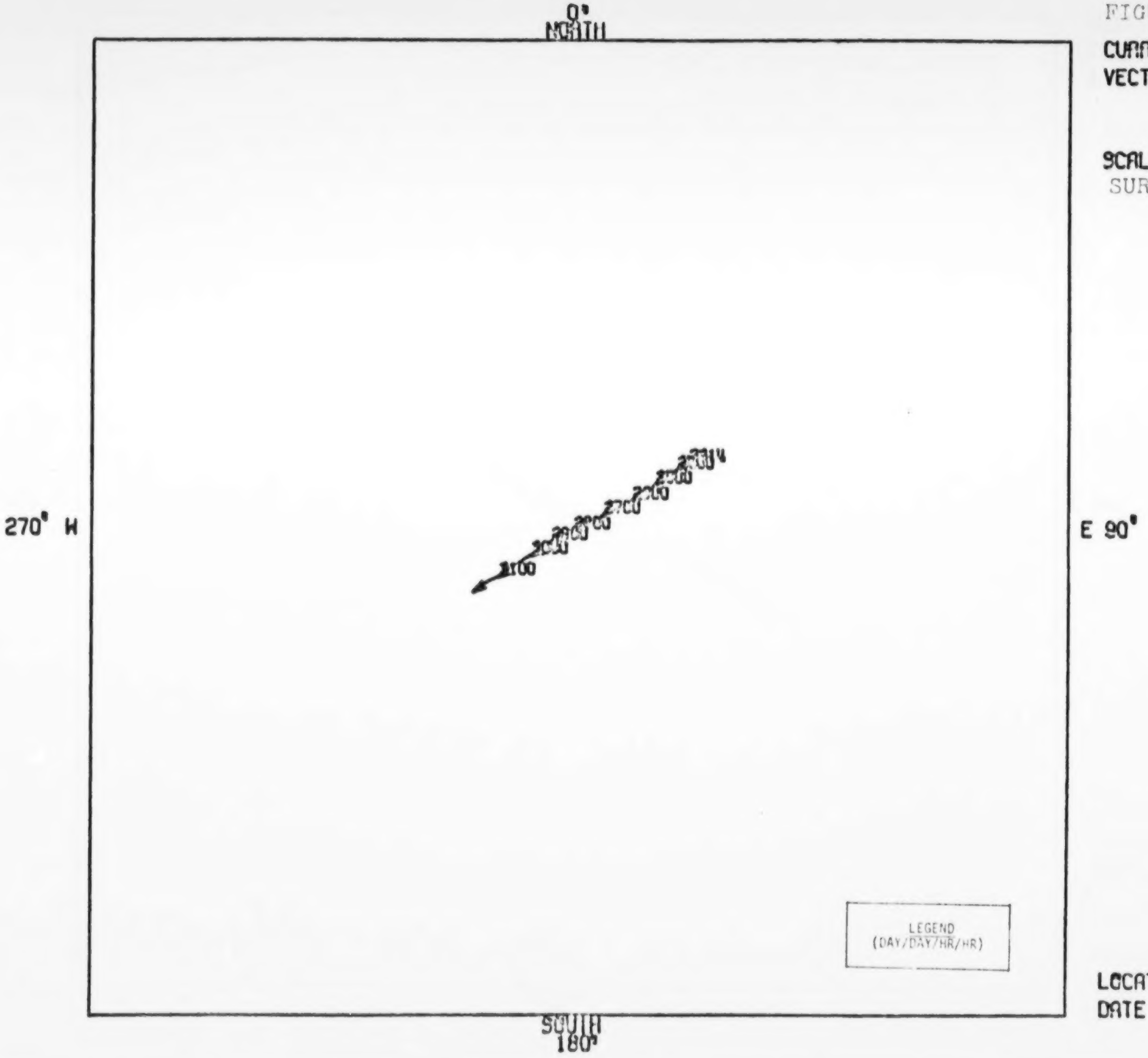
SCALE - 1 IN = 1717.80 KM

LOCAT'ON - BUCCANEER
DATE - 7612

FIGURE 55

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 99.3355K
SURFACE

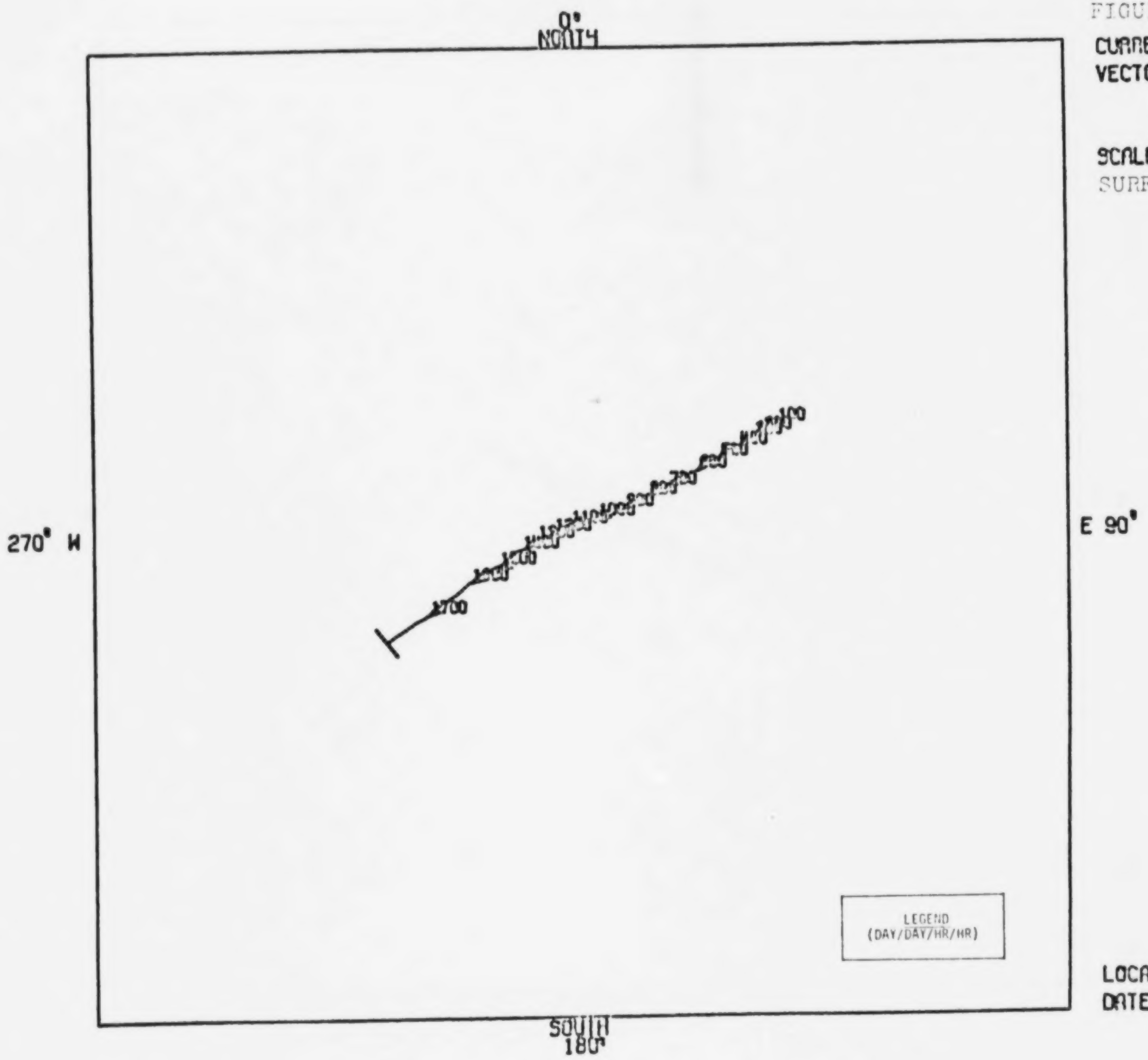


LOCATION - BUCCANEER
DATE - 7603

FIGURE 56

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 99.3355 KM
SURFACE

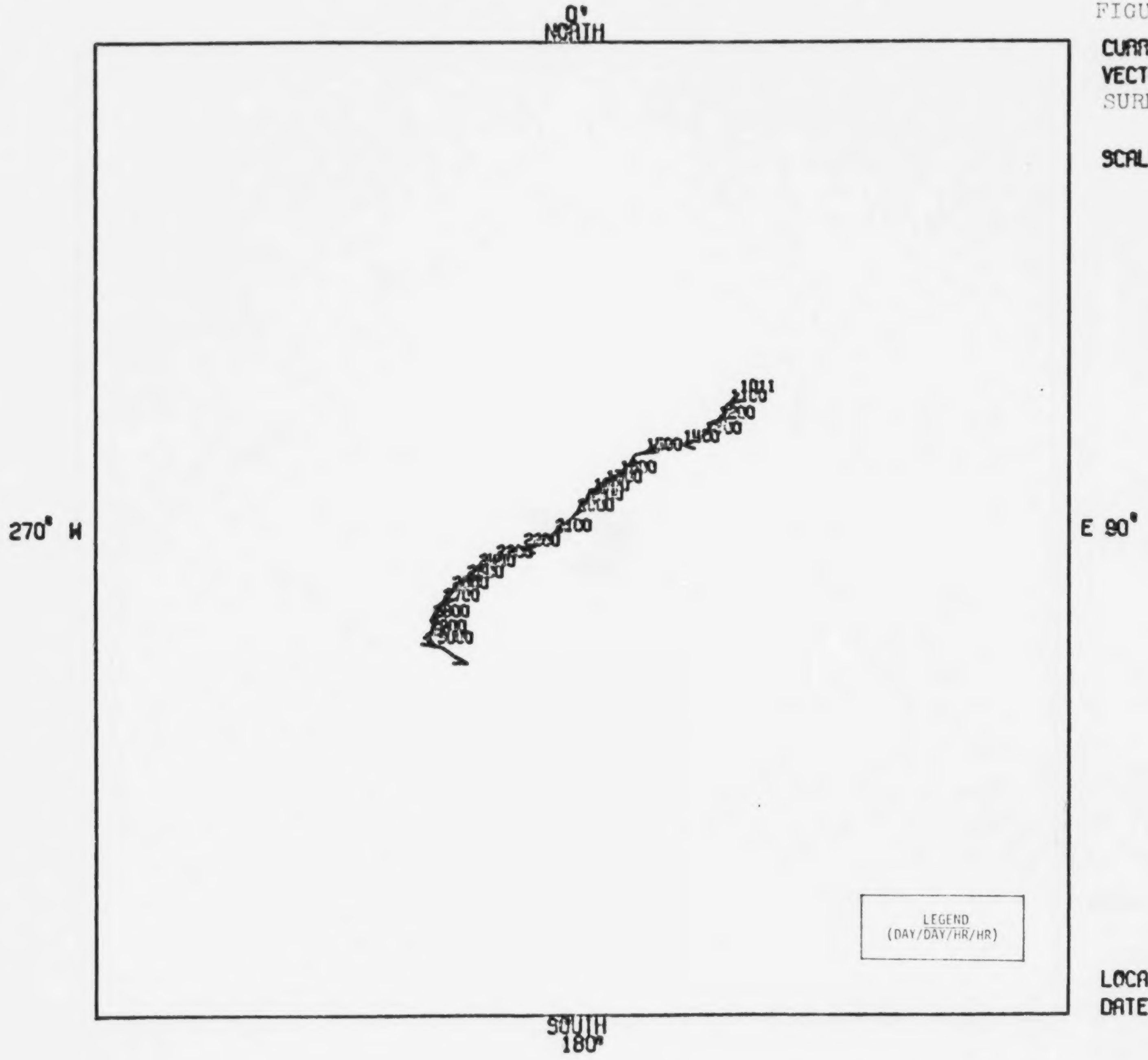


LOCATION - BUCCANEER
DATE - 7604

FIGURE 57

CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 K

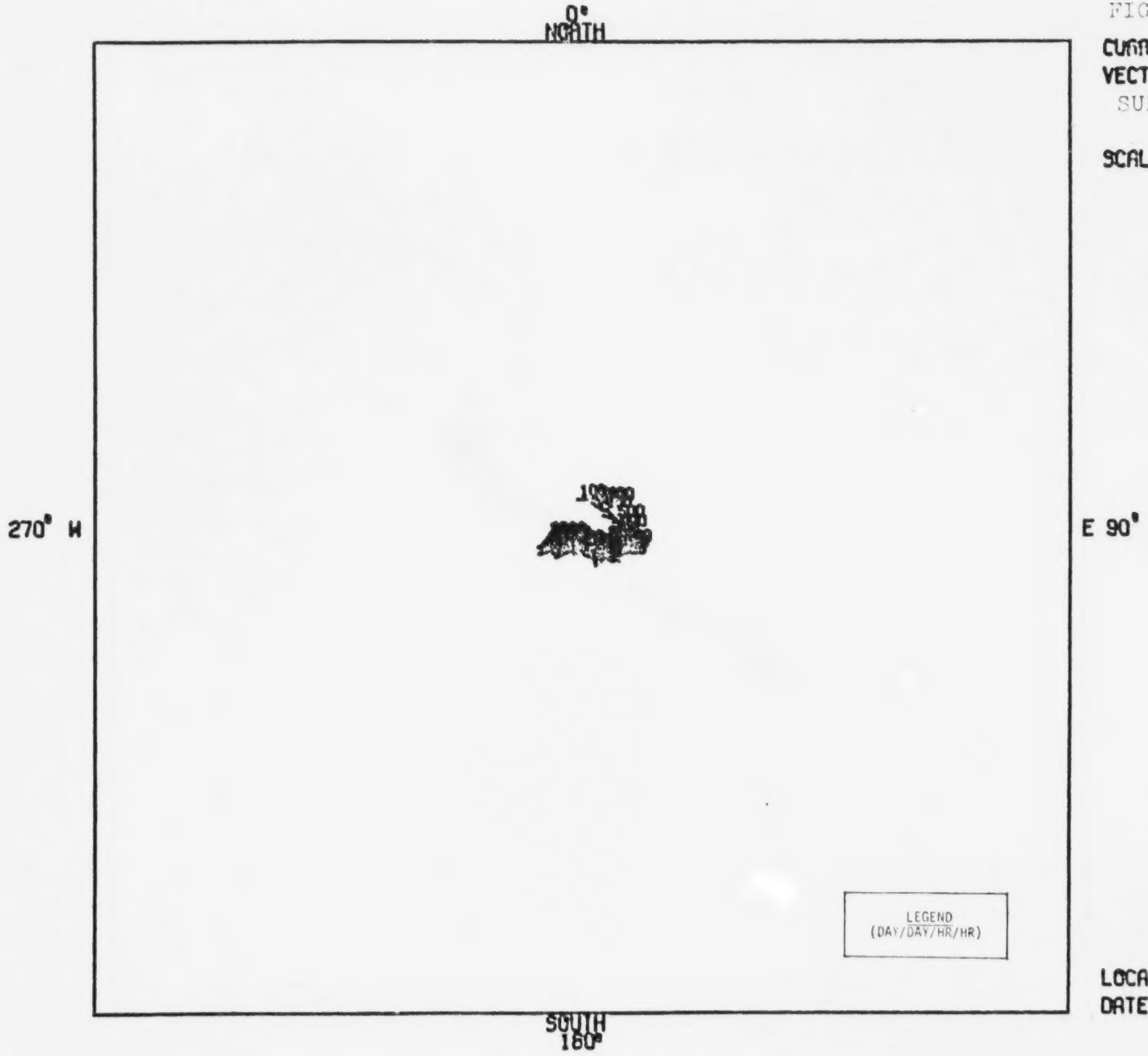


LOCATION - BUCCANEER
DATE - 7606

FIGURE 58

CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KM

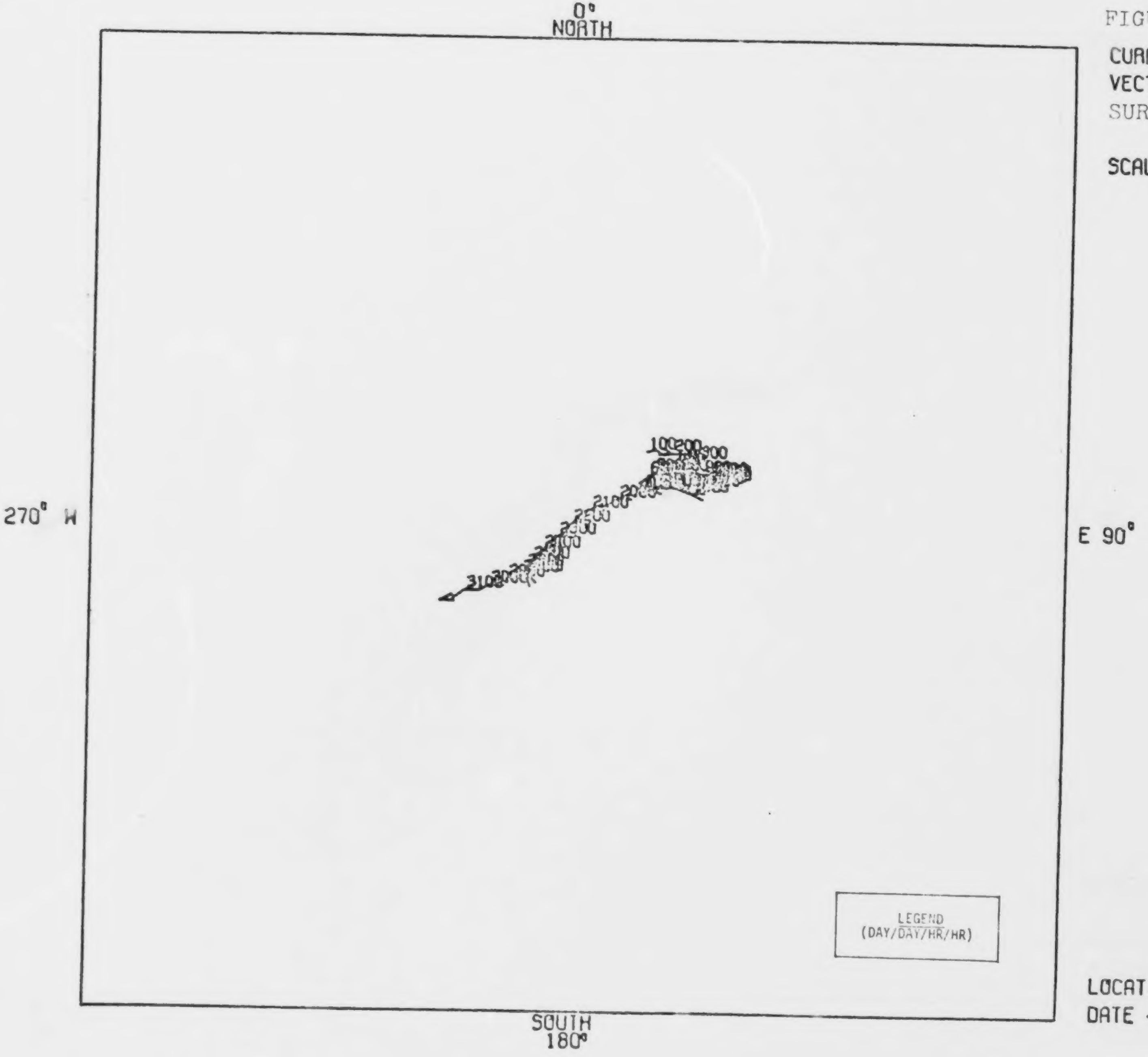


LOCATION - BUCCANEER
DATE - 7607

FIGURE 59

CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KI

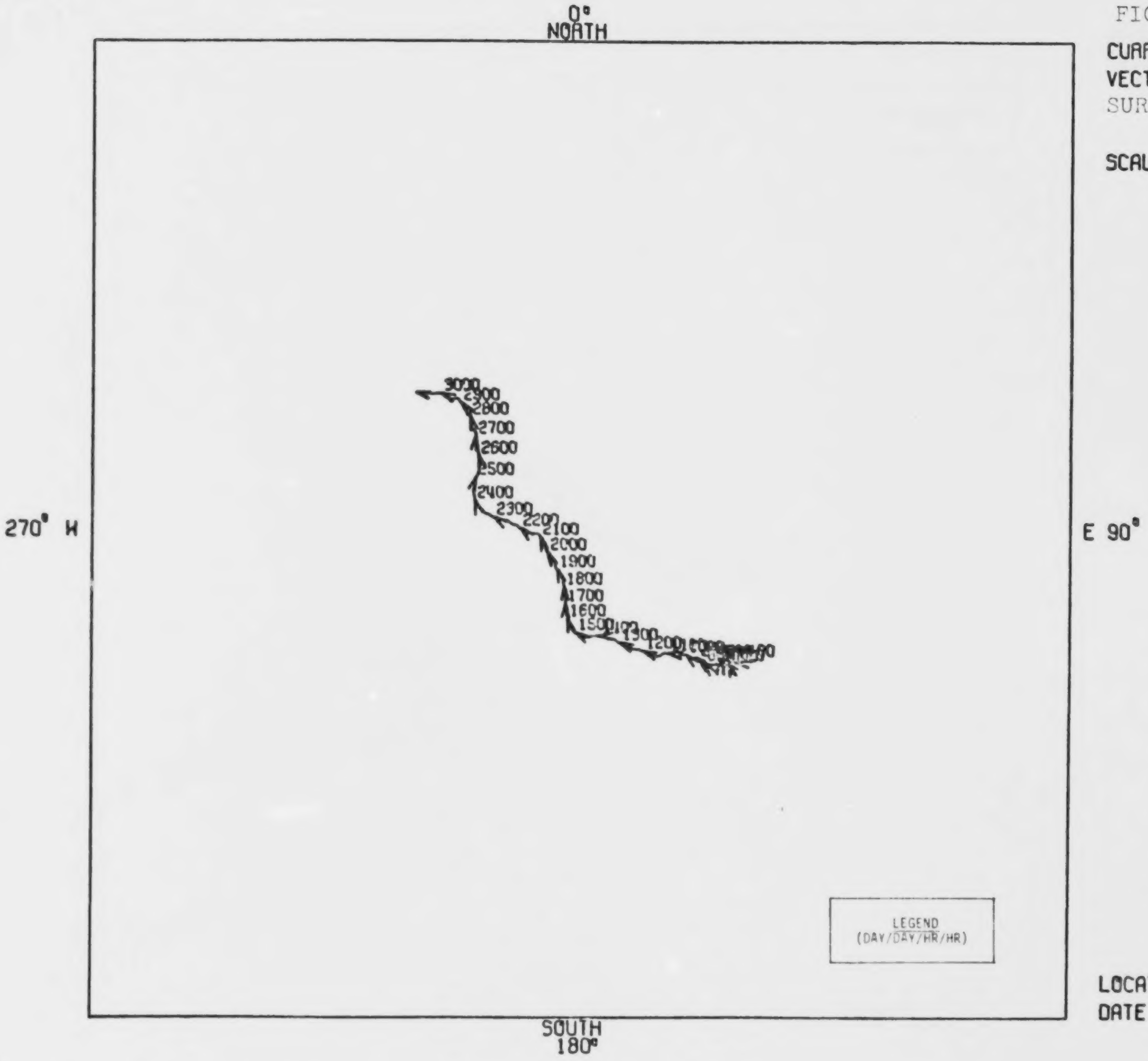


LOCATION - BUCCANEER
DATE - 7608

FIGURE 60

CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KM



LOCATION - BUCCANEER
DATE - 7609

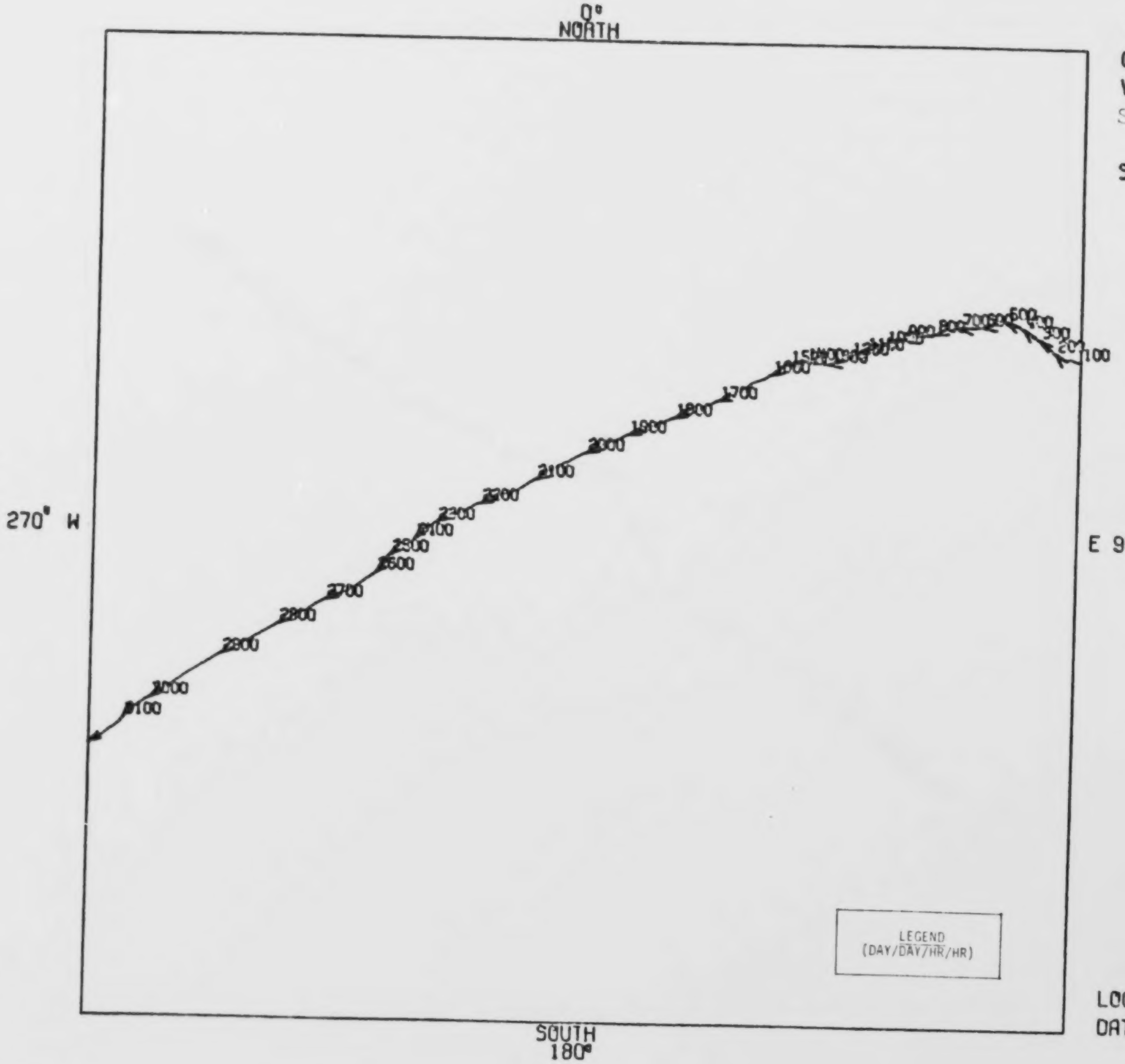


FIGURE 51

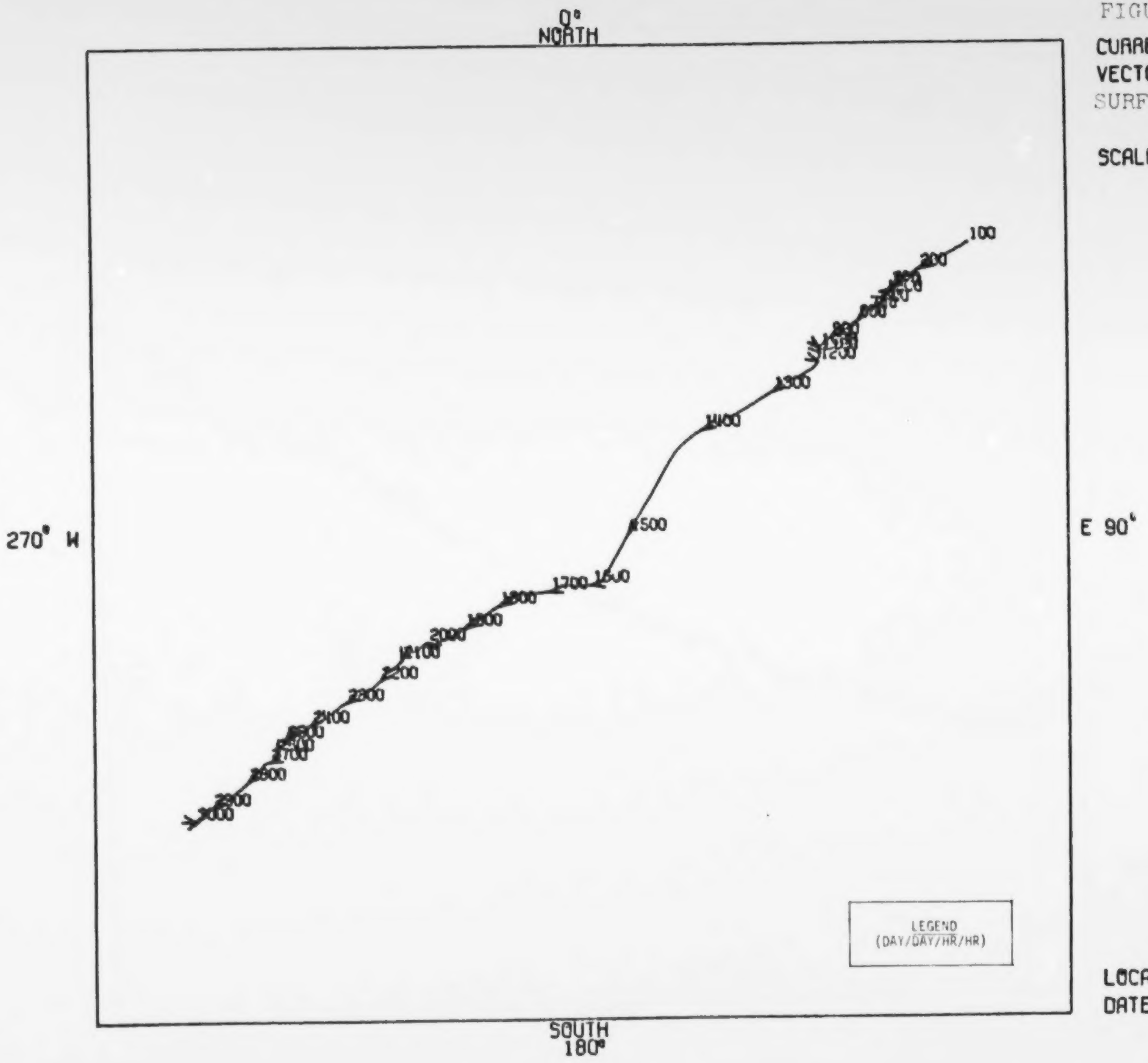
CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KI

LOCATION - BUCCANEER
DATE - 7610

FIGURE 62
CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KM



LOCATION - BUCCANEER
DATE - 7611

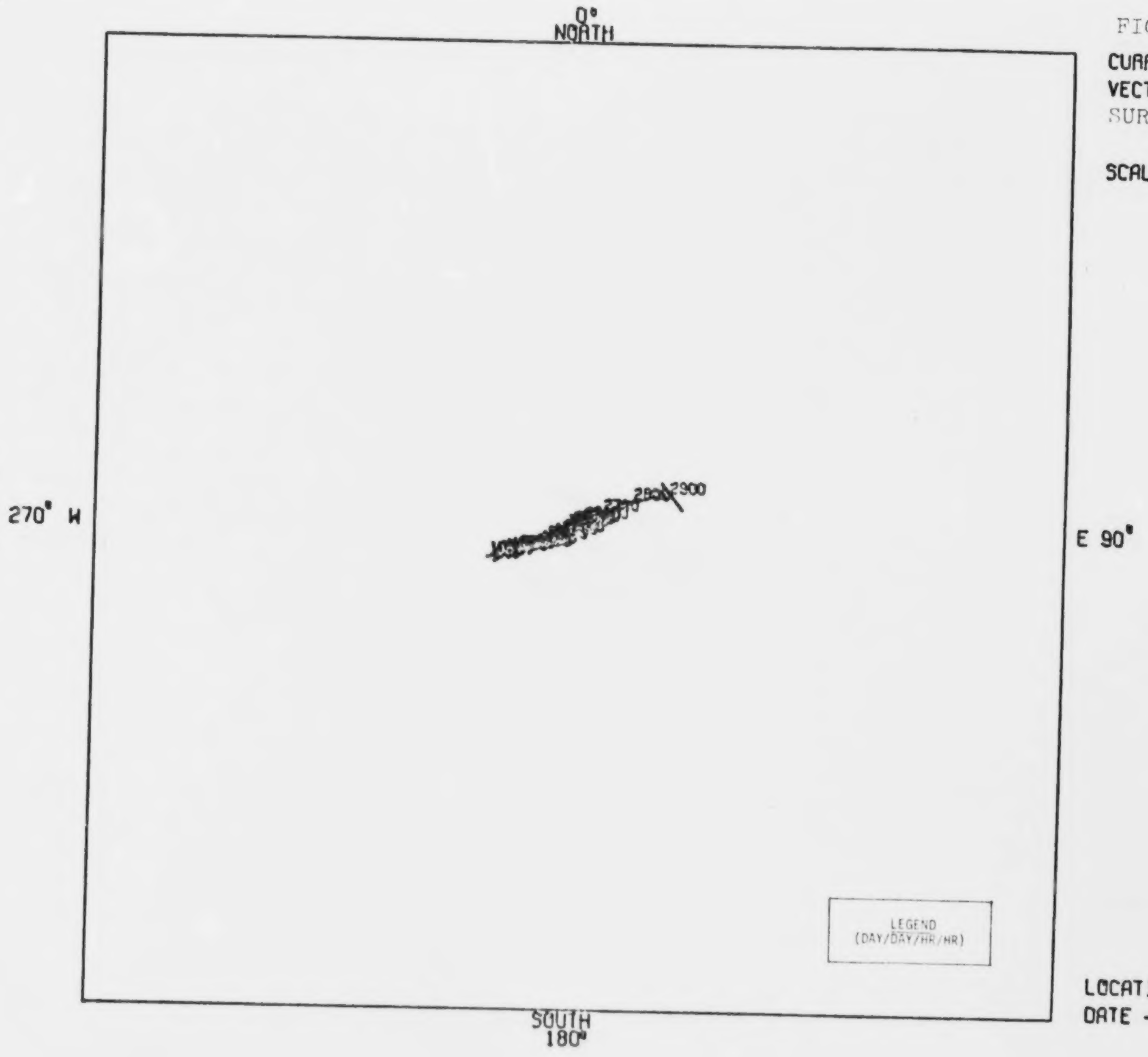


FIGURE 63

CURRENT PROGRESSIVE
VECTOR DIAGRAM
SURFACE

SCALE - 1 IN = 99.3355 KM

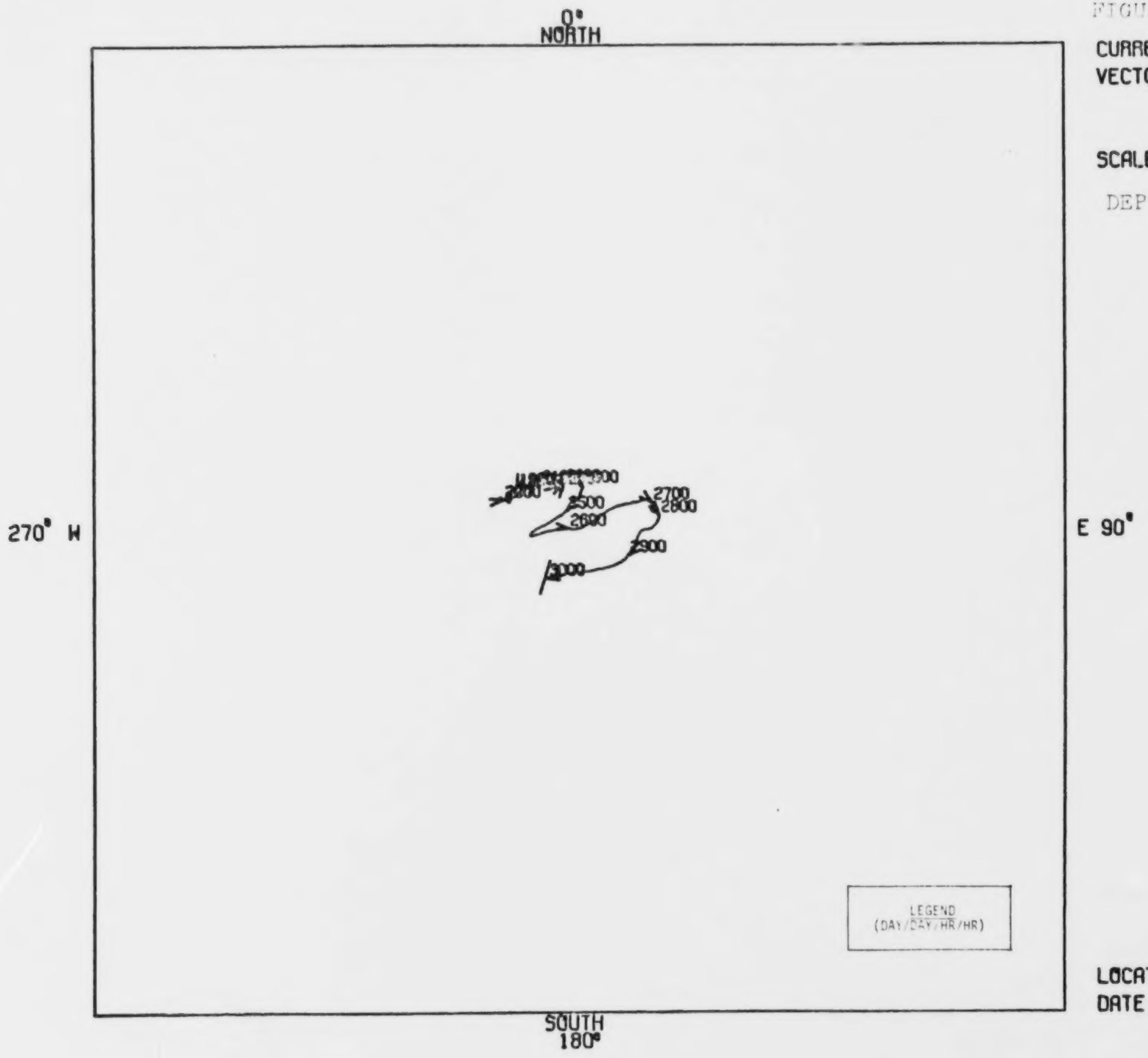
LOCATION - BUCCANEER
DATE - 7612

FIGURE 54

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M

DEPTH - 10.0m



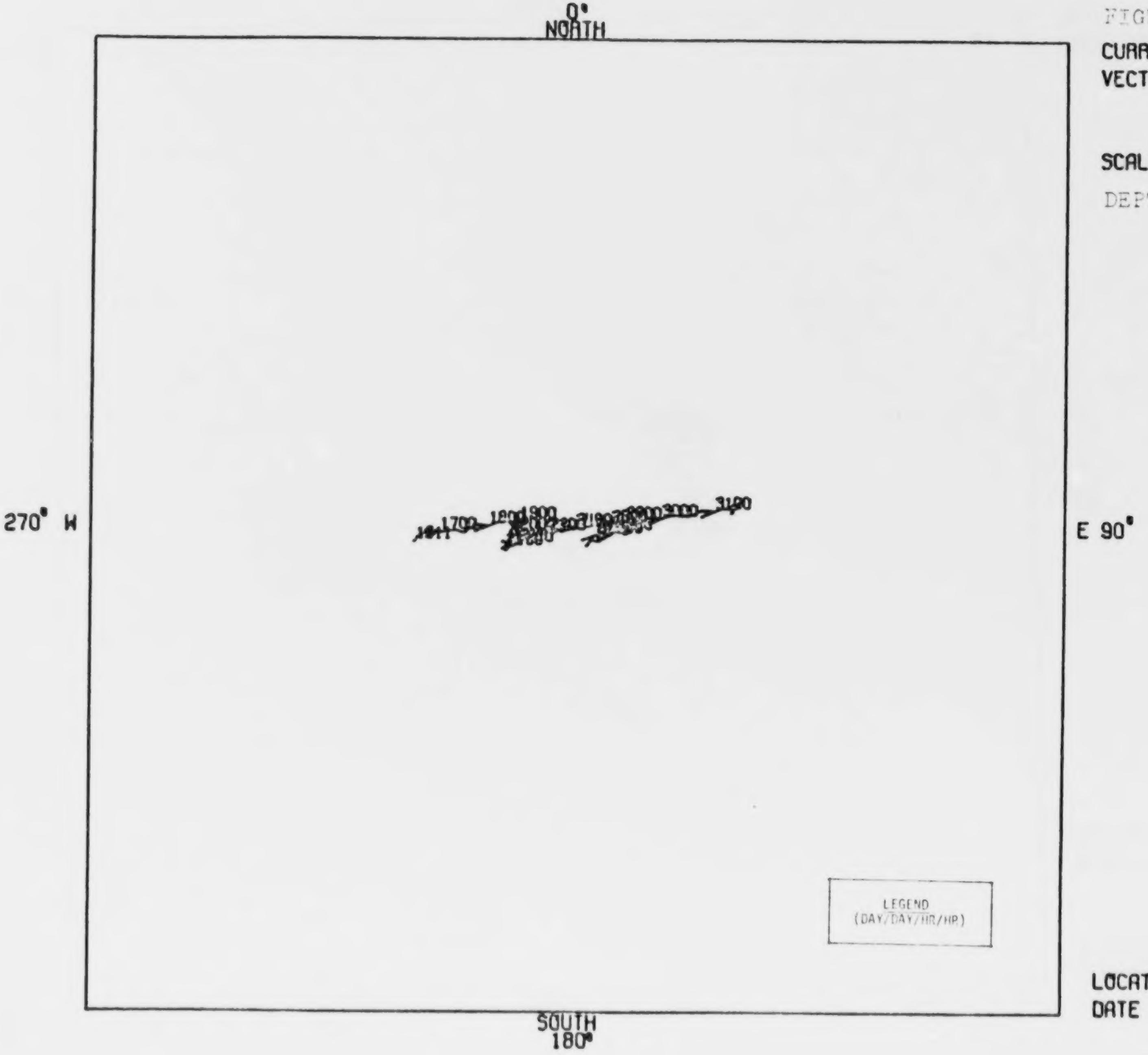
LOCATION - BUCCANEER
DATE - 7512

FIGURE 65

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.

DEPTH - 10.0m

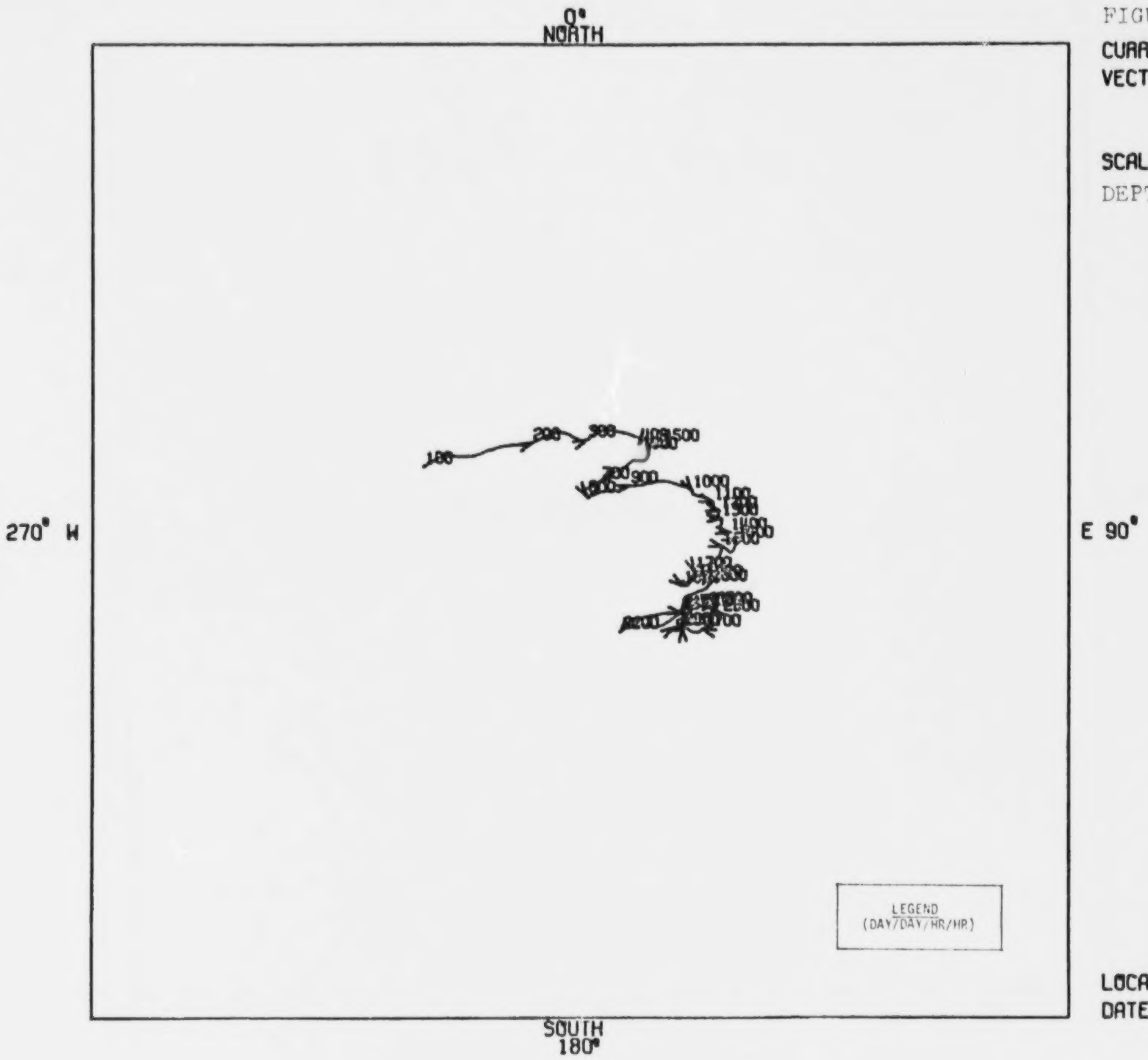


LOCATION - BUCCANEER
DATE - 7601

FIGURE 66

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M
DEPTH - 10.0m



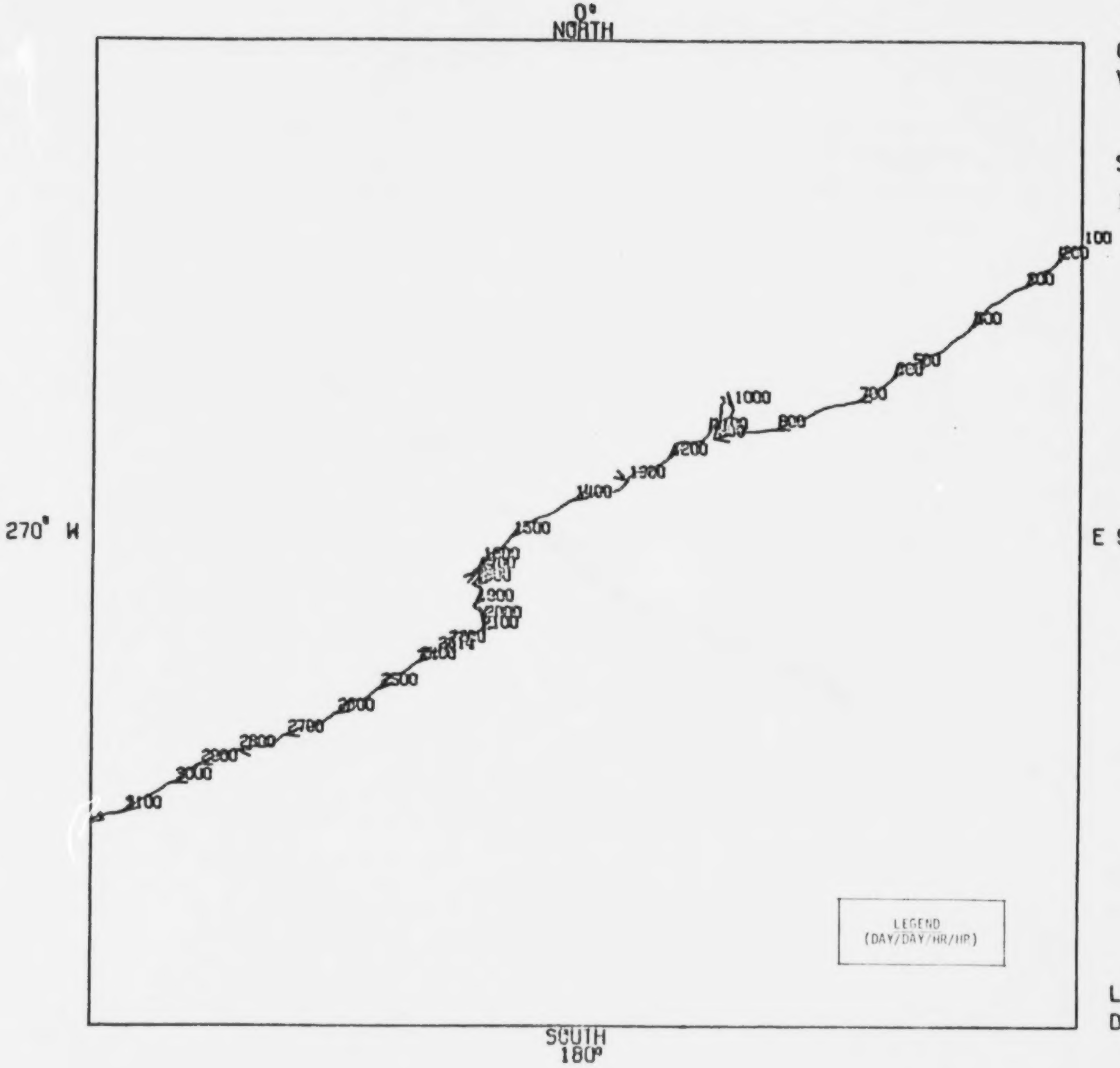
LOCATION - BUCCANEER
DATE - 7602

FIGURE 67

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M

DEPTH - 10.0m

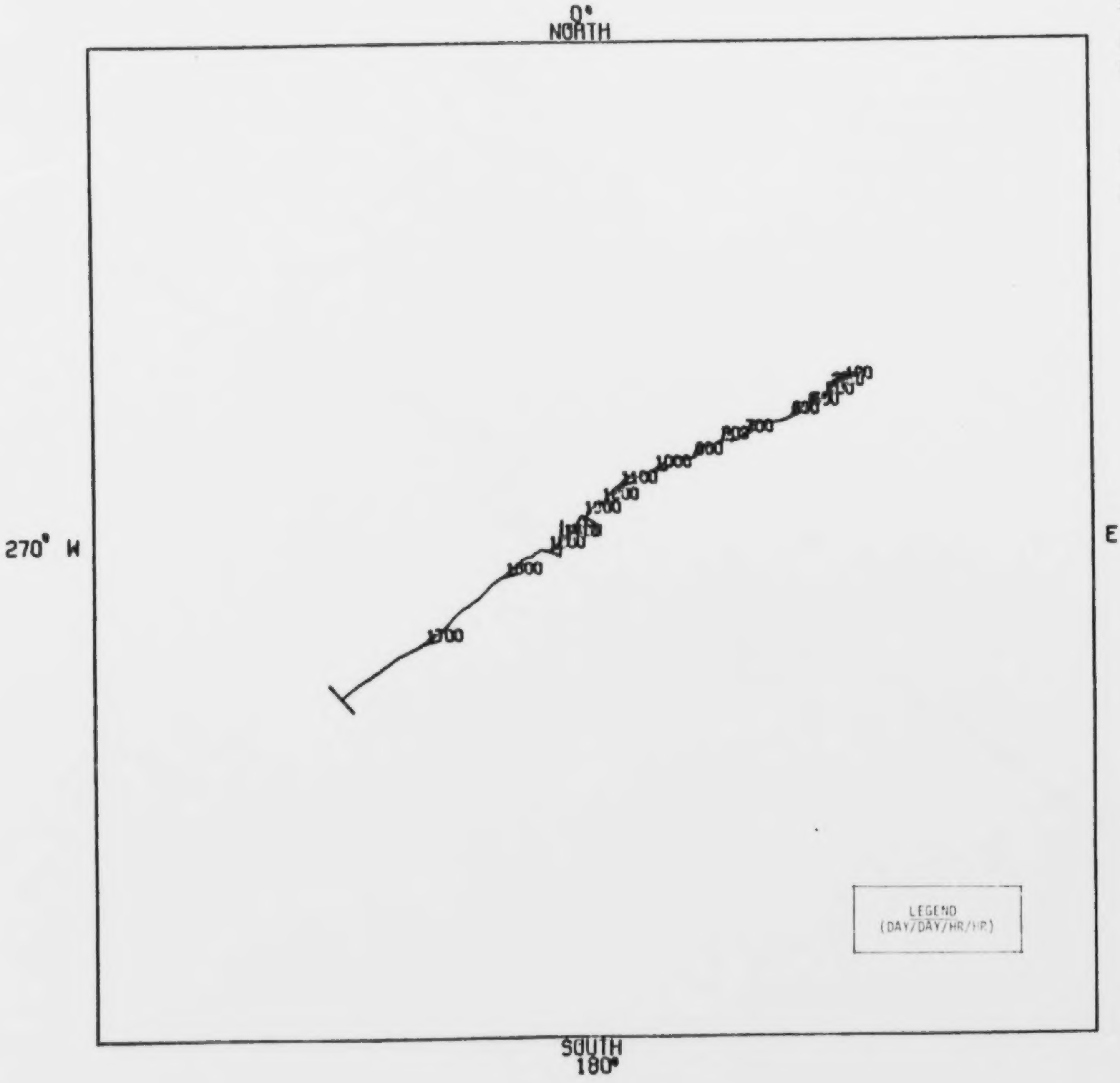


LOCATION - BUCCANEER
DATE - 7603

FIGURE 68

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M
DEPTH - 10.0m

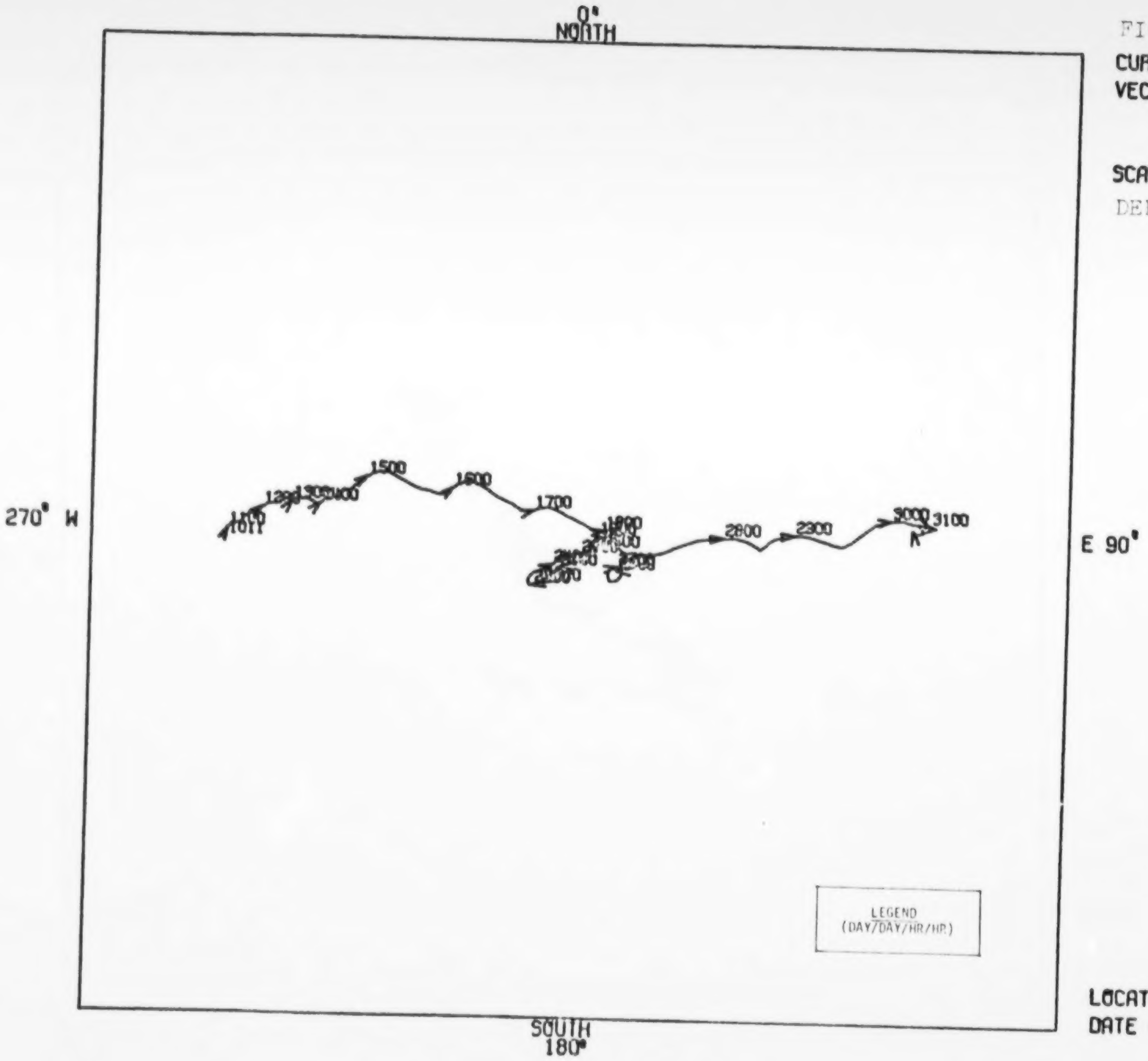


LOCATION - BUCCANEER
DATE - 7604

FIGURE [illegible]

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80
DEPTH - 10.0m

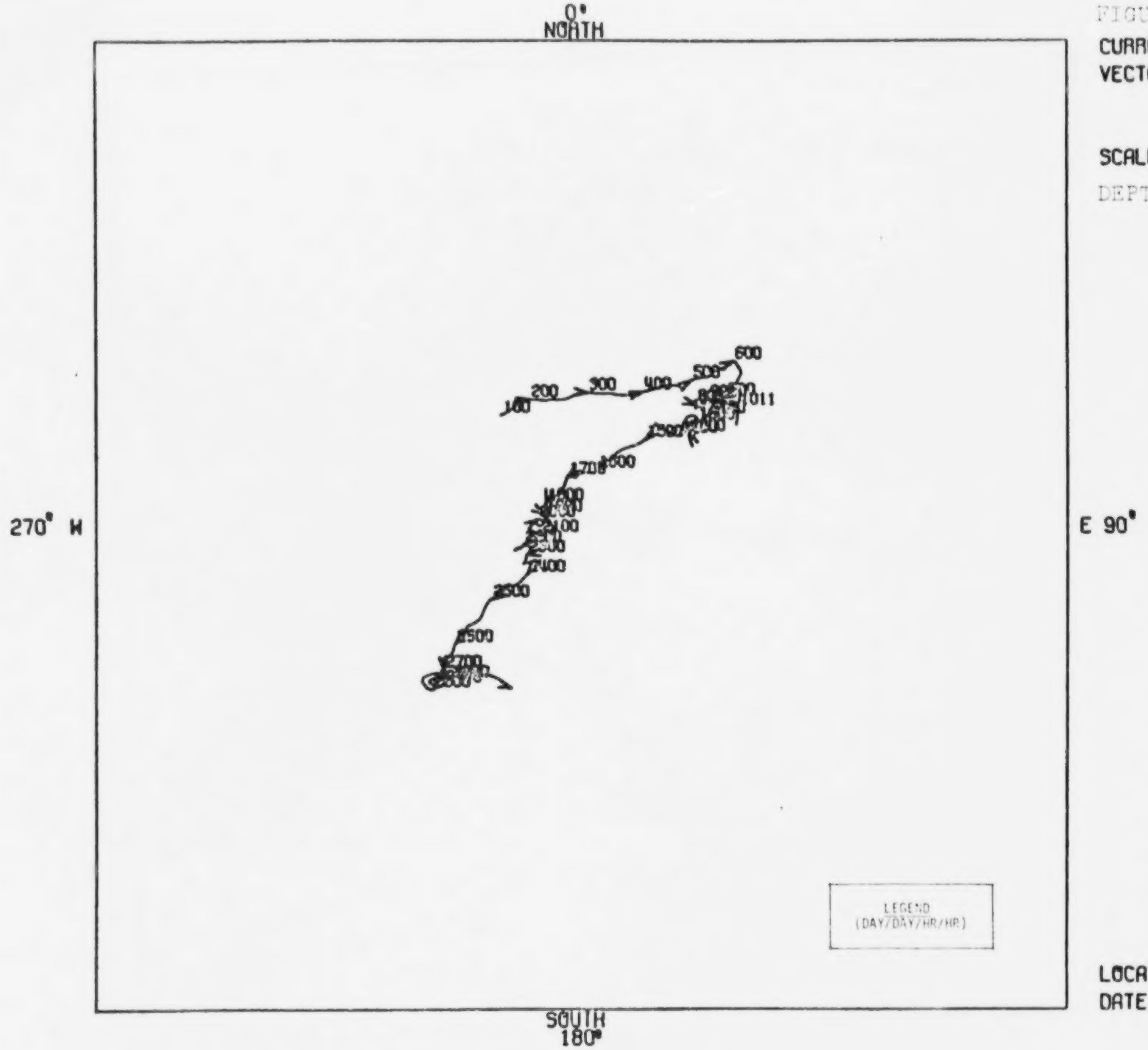


LOCATION - BUCCANEER
DATE - 7605

FIGURE

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M
DEPTH - 10.0m



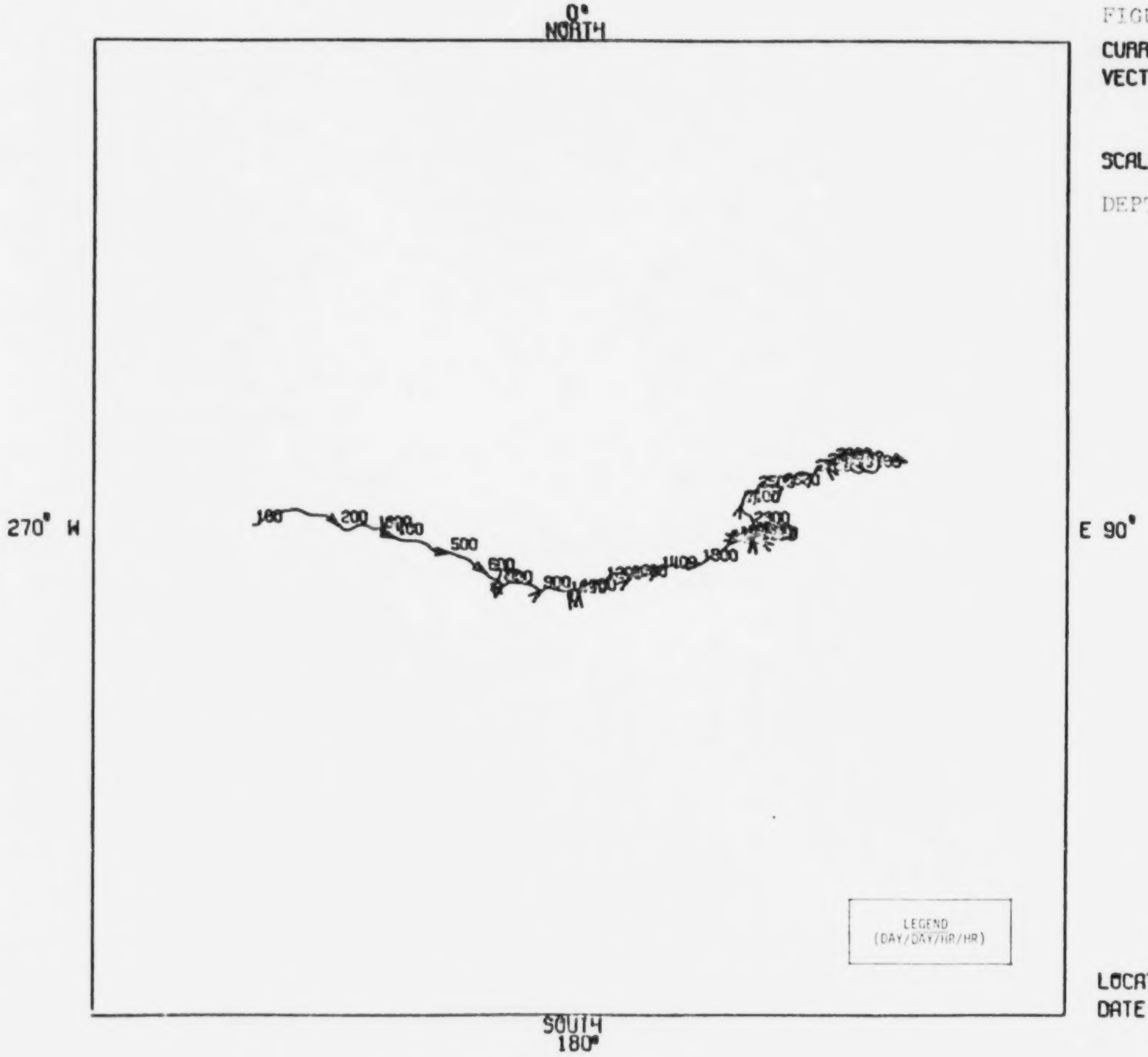
LOCATION - BUCCANEER
DATE - 7606

FIGURE 71

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80

DEPTH - 10.0m

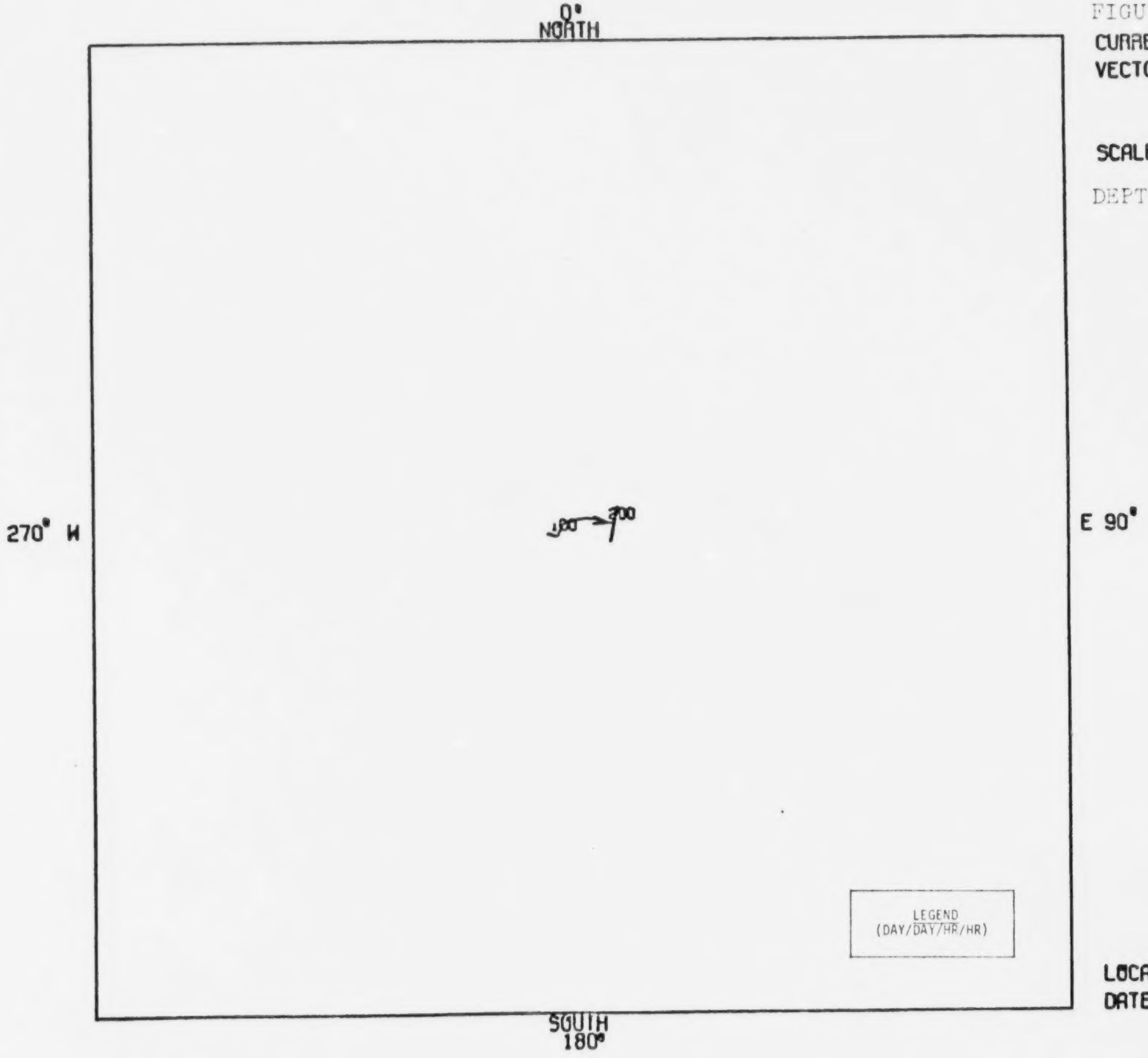


LOCATION - BUCCANEER
DATE - 7607

FIGURE 72
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M

DEPTH - 10.0m

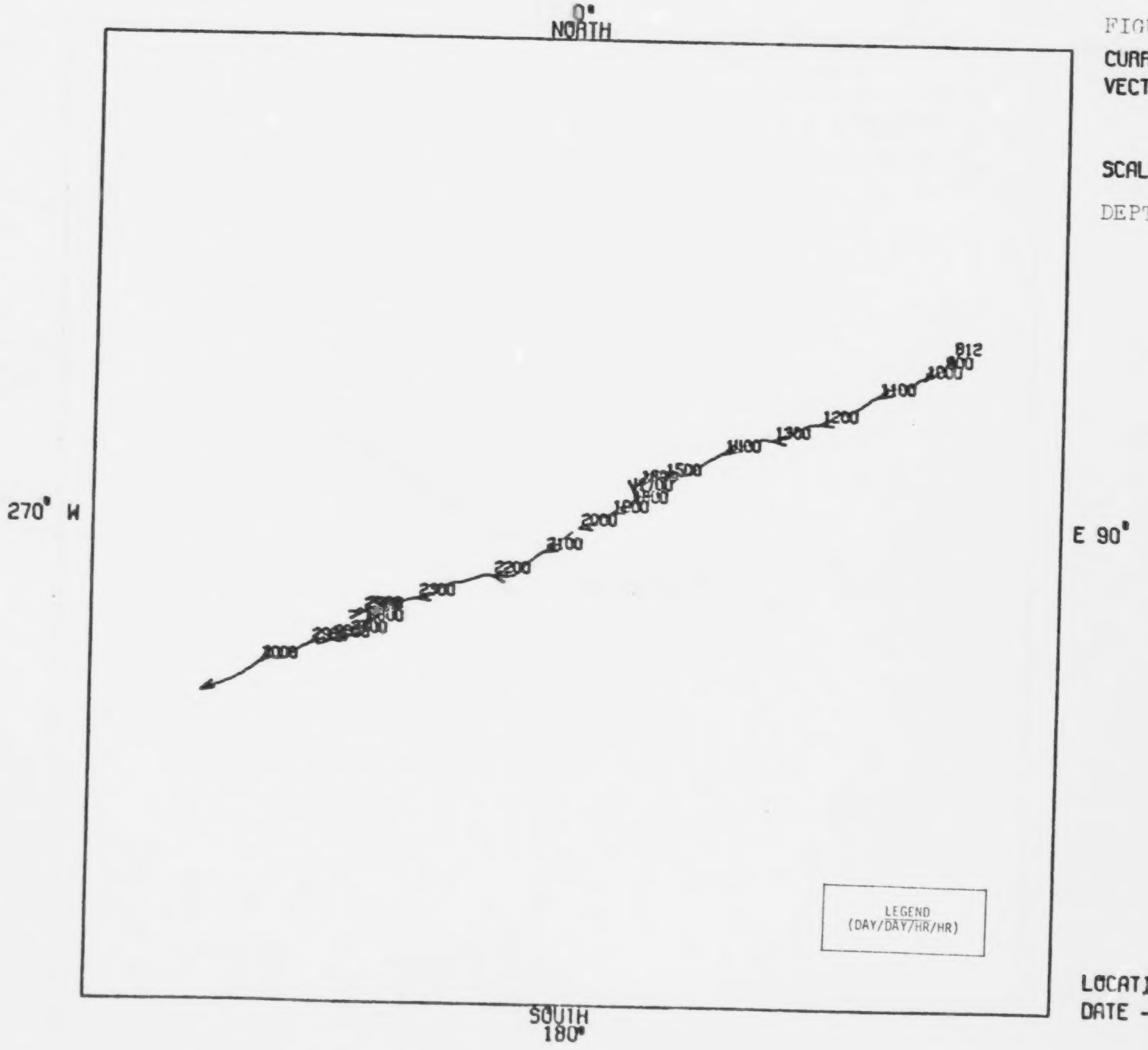


LOCATION - BUCCANEER
DATE - 7608

FIGURE 73
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80

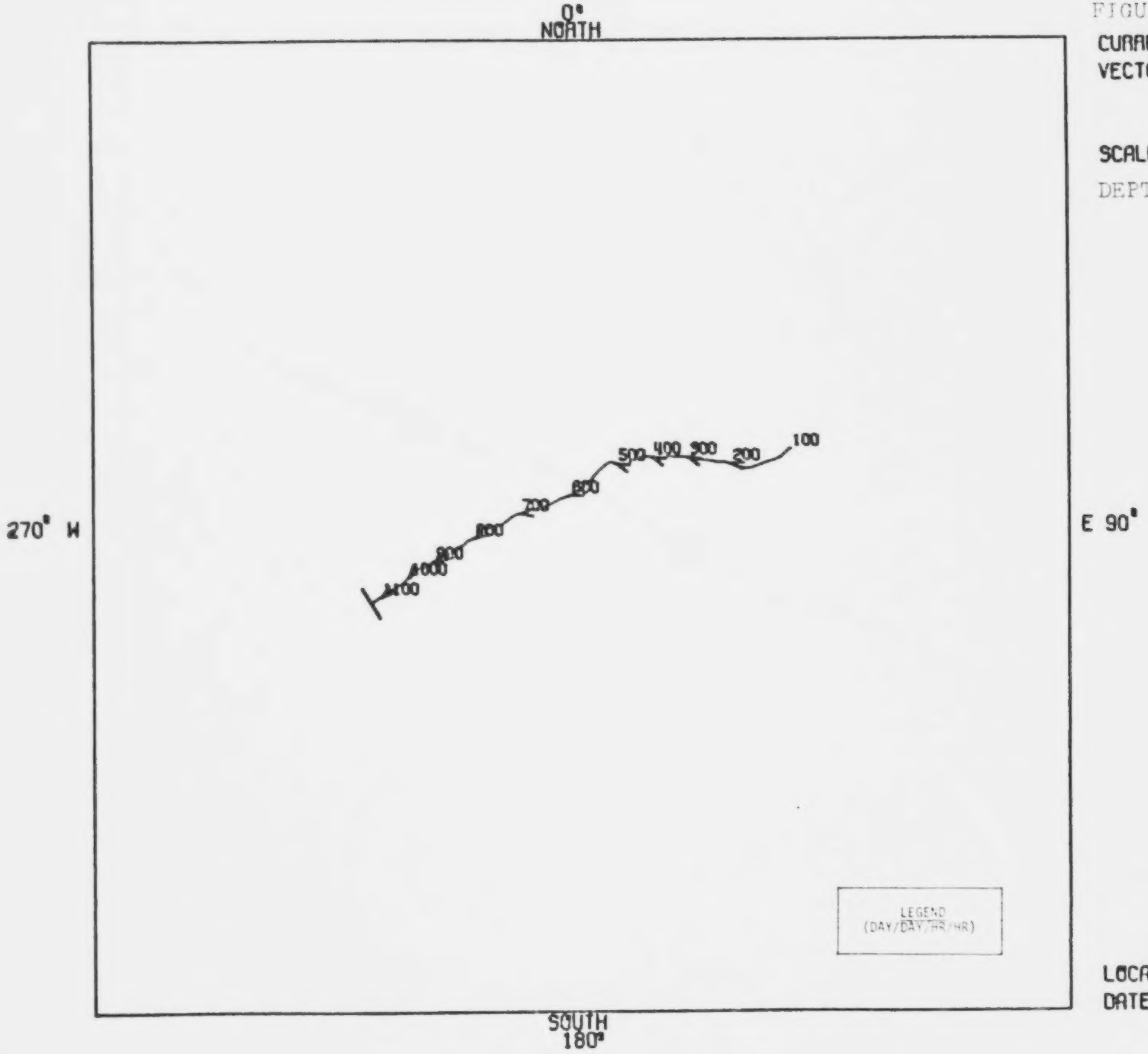
DEPTH - 10.0m



LOCATION - BUCCANEER
DATE - 7609

FIGURE 74
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 45620.80 M
DEPTH - 10.0m



LOCATION - BUCCANEER
DATE - 7610

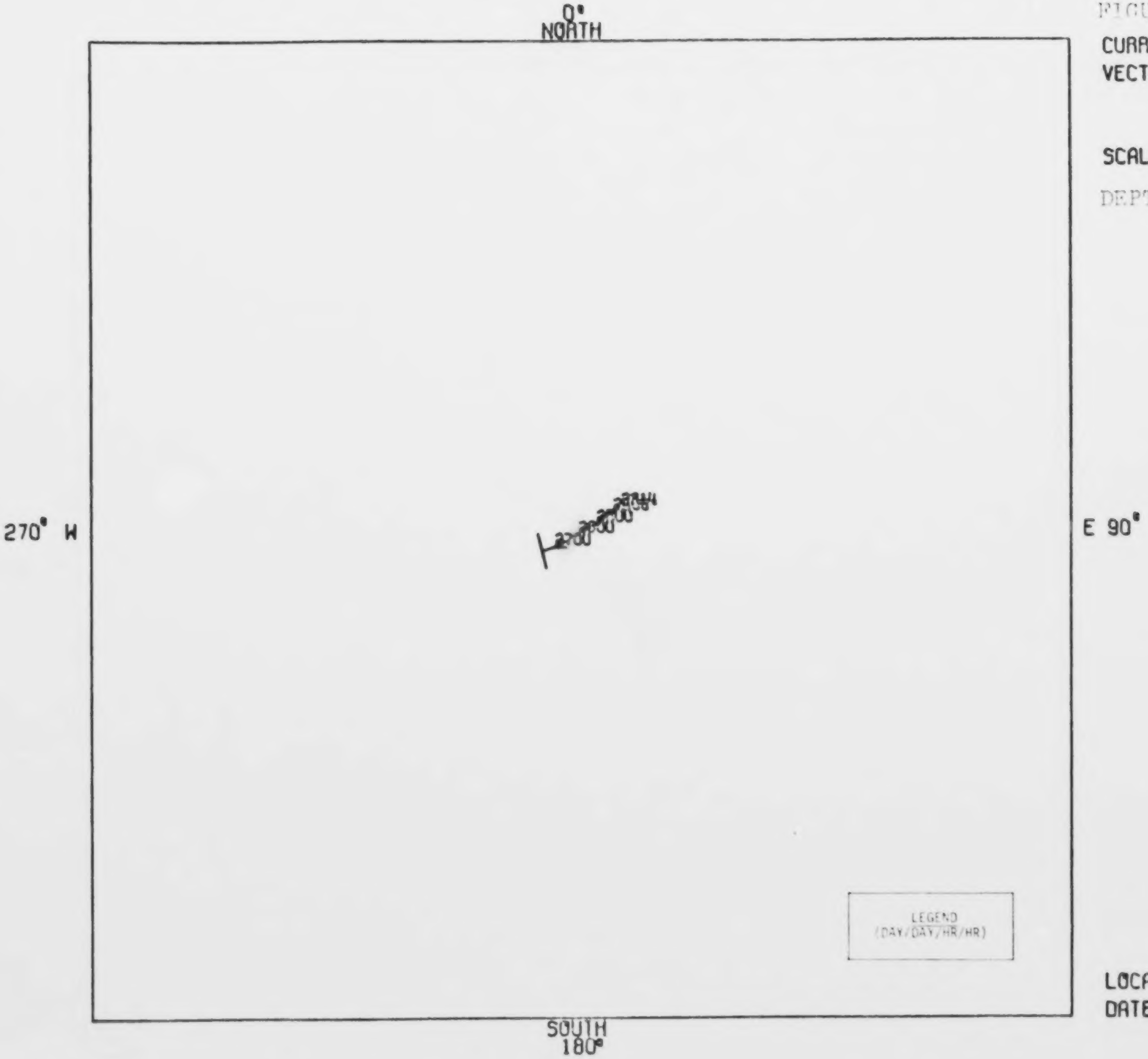


FIGURE 75

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00 M

DEPTH - 17.7m

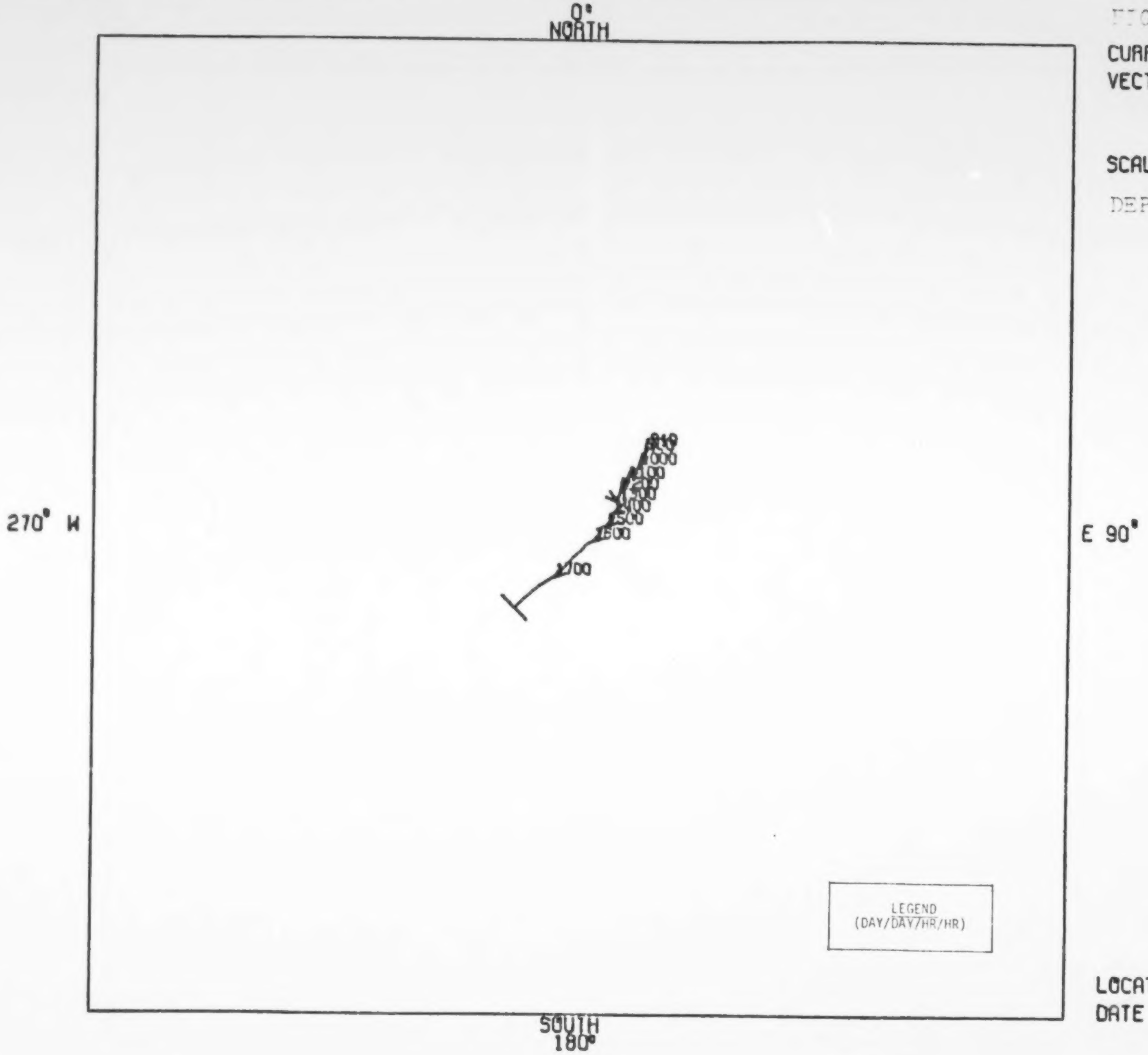
LOCATION - BUCCANEER
DATE - 7603

FIGURE 76

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00 M

DEPTH - 17.7m



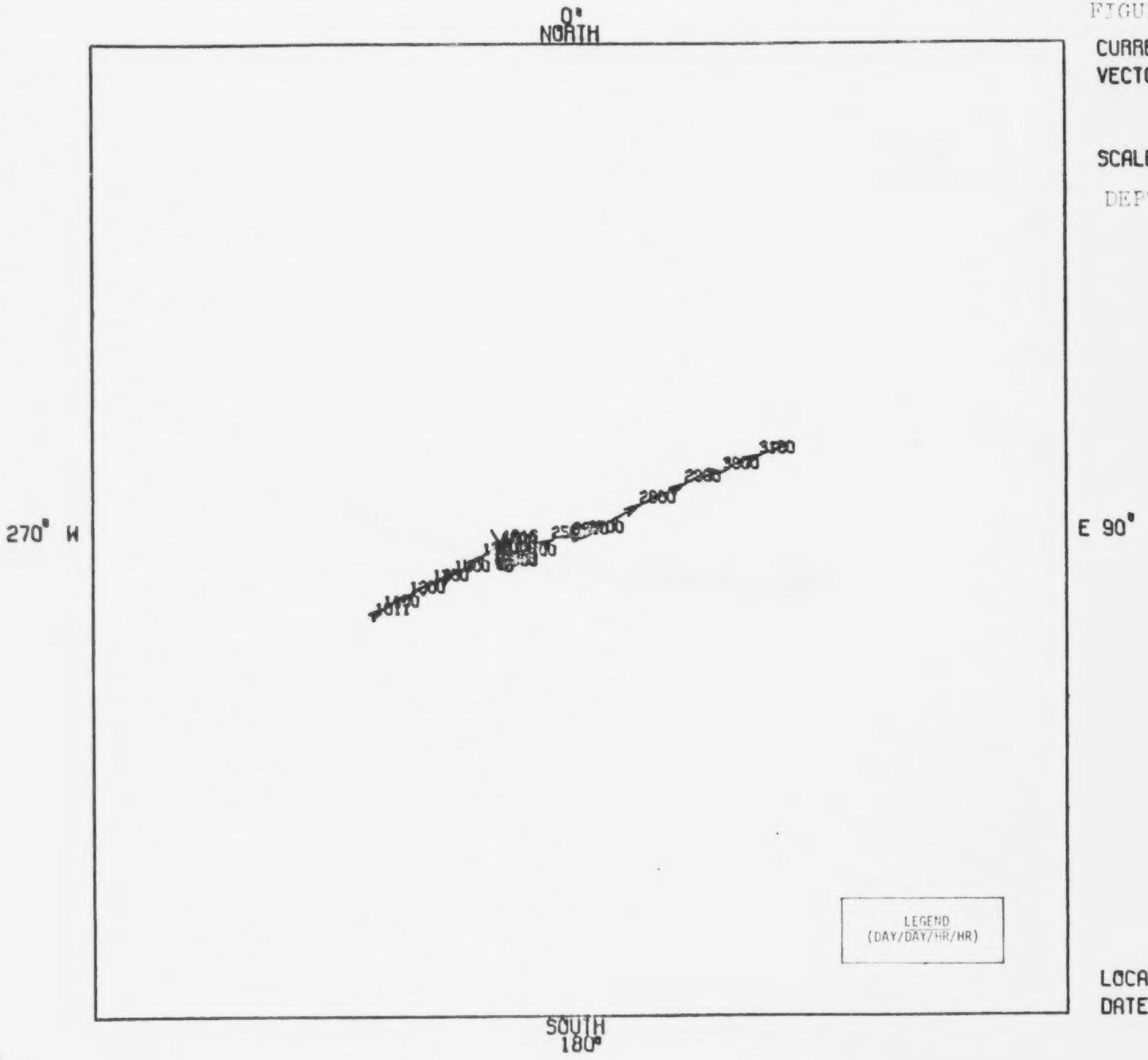
LOCATION - BUCCANEER
DATE - 7604

FIGURE

CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00 M

DEPTH - 17.7m

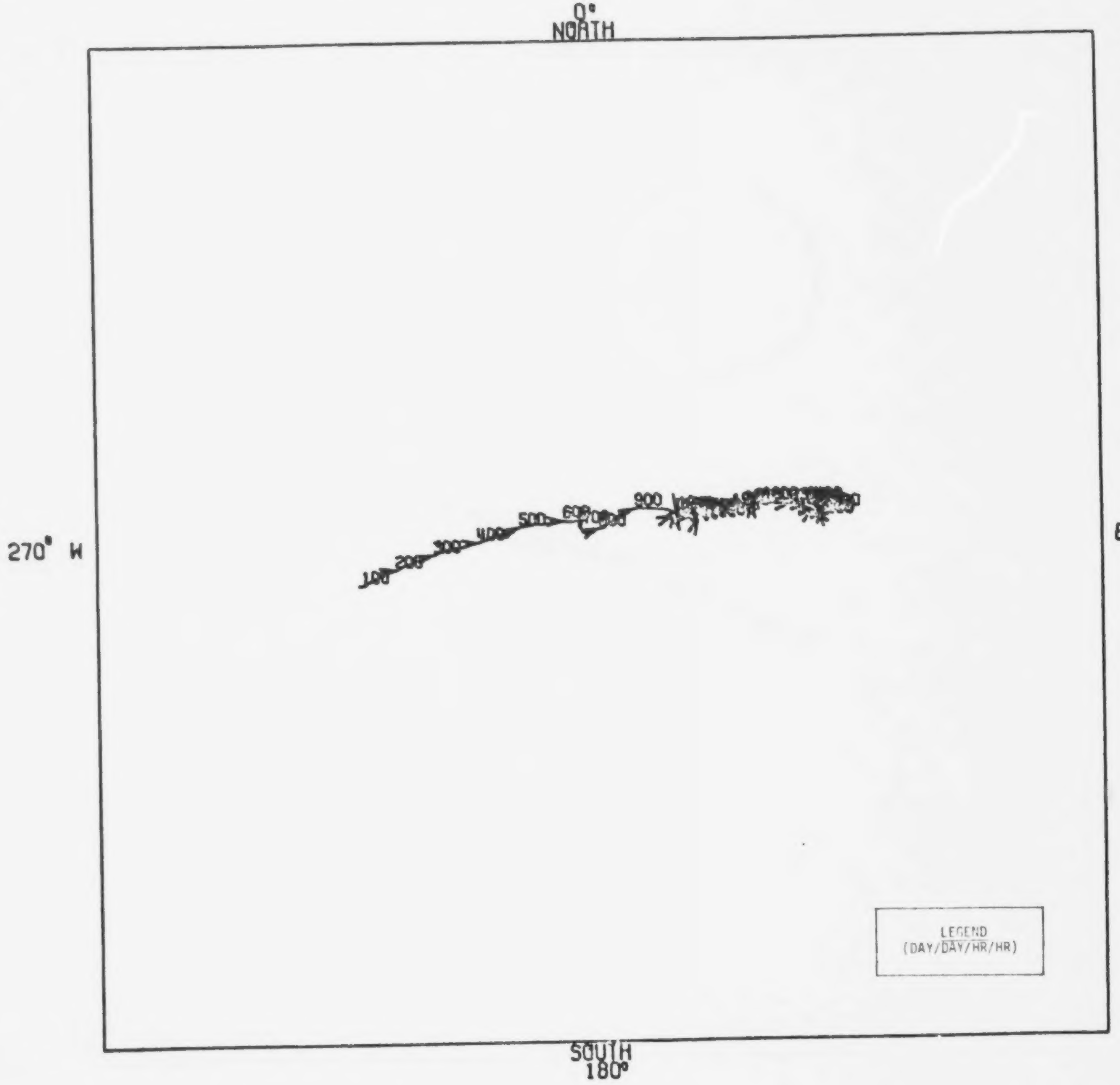


LOCATION - BUCCANEER
DATE - 7605

FIGURE 78
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00 M

DEPTH - 17.7m

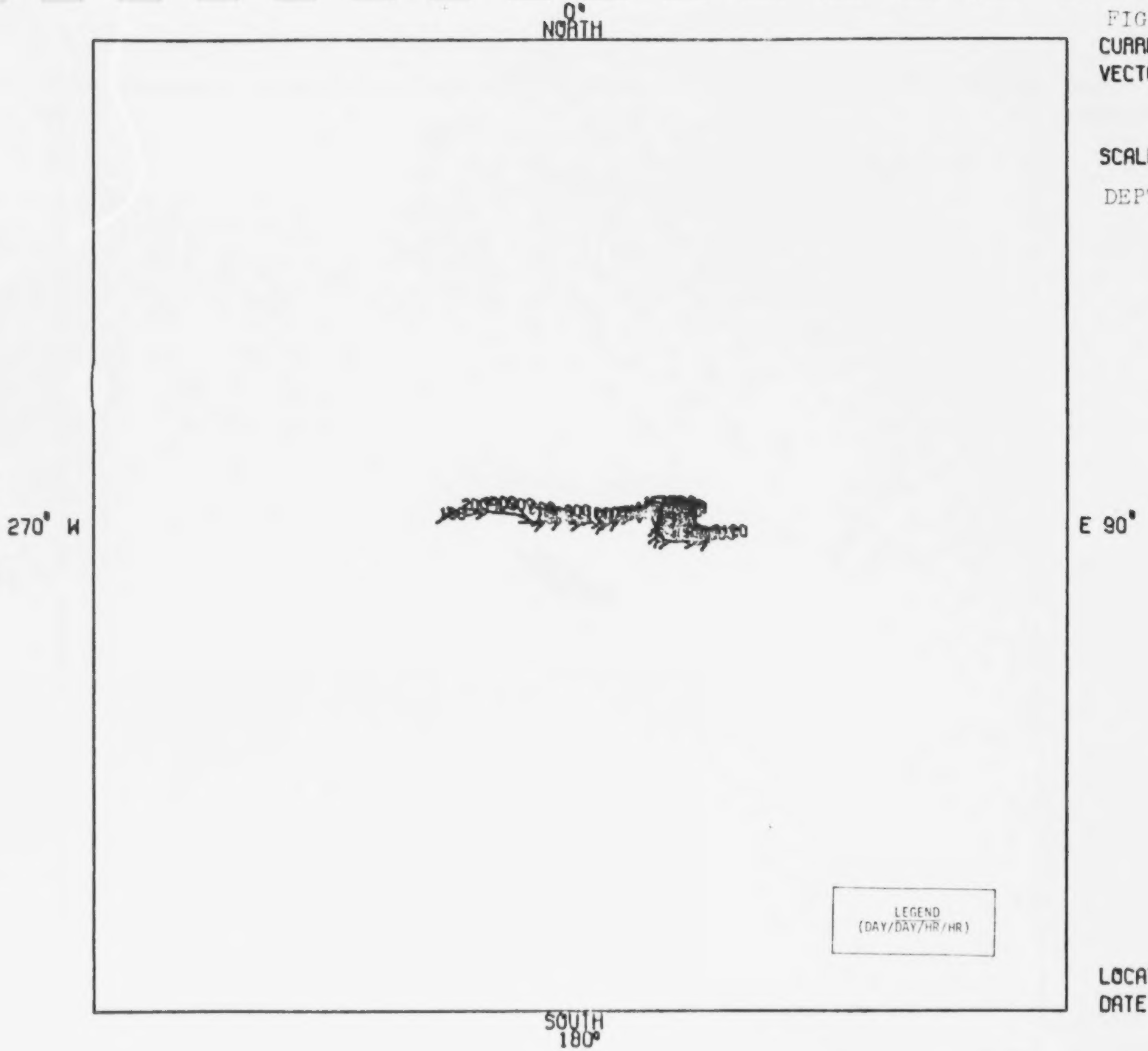


LOCATION - BUCCANEER
DATE - 7606

FIGURE 79
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00

DEPTH - 17.7m



LOCATION - BUCCANEER
DATE - 7607

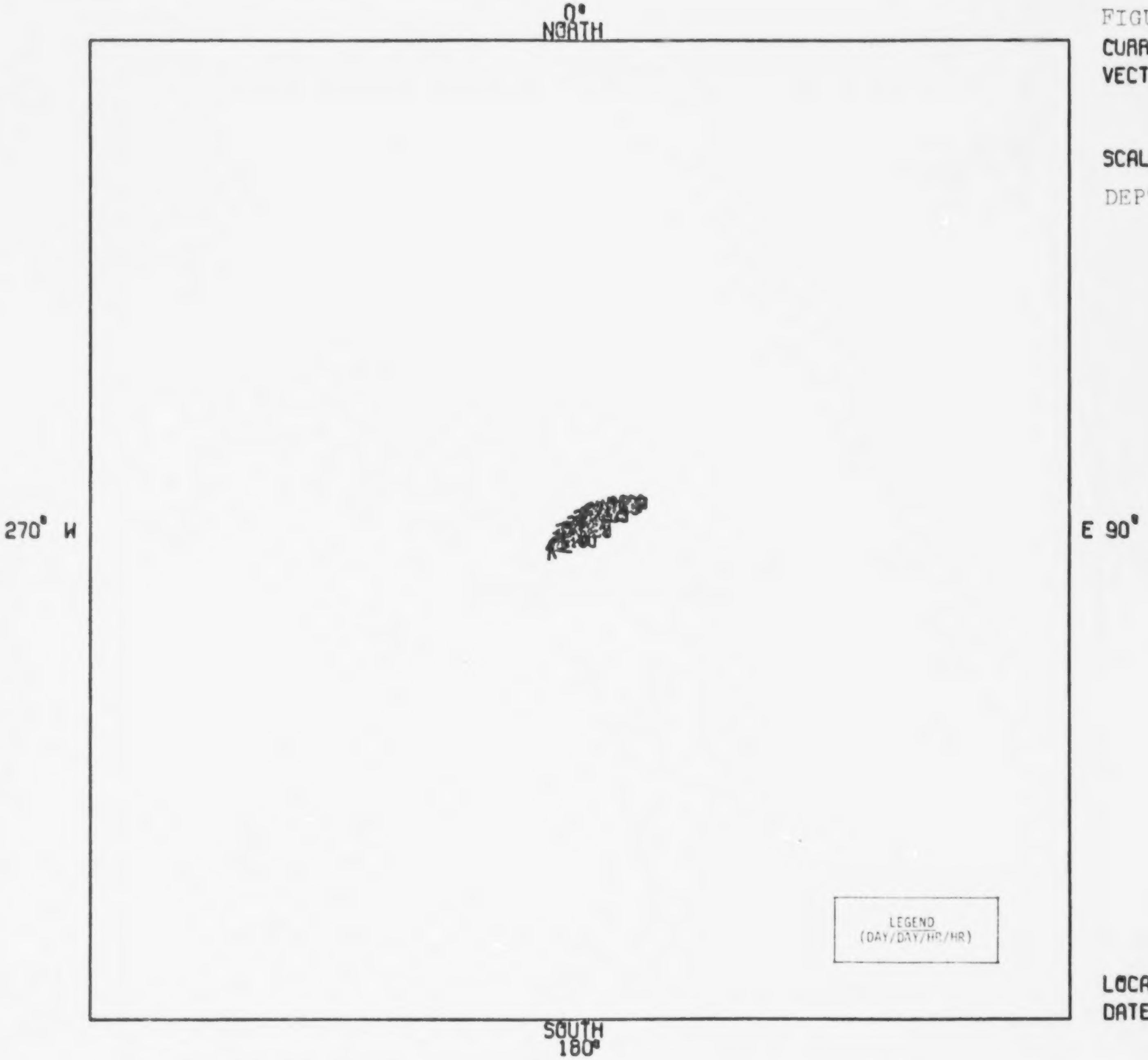


FIGURE 80
CURRENT PROGRESSIVE
VECTOR DIAGRAM

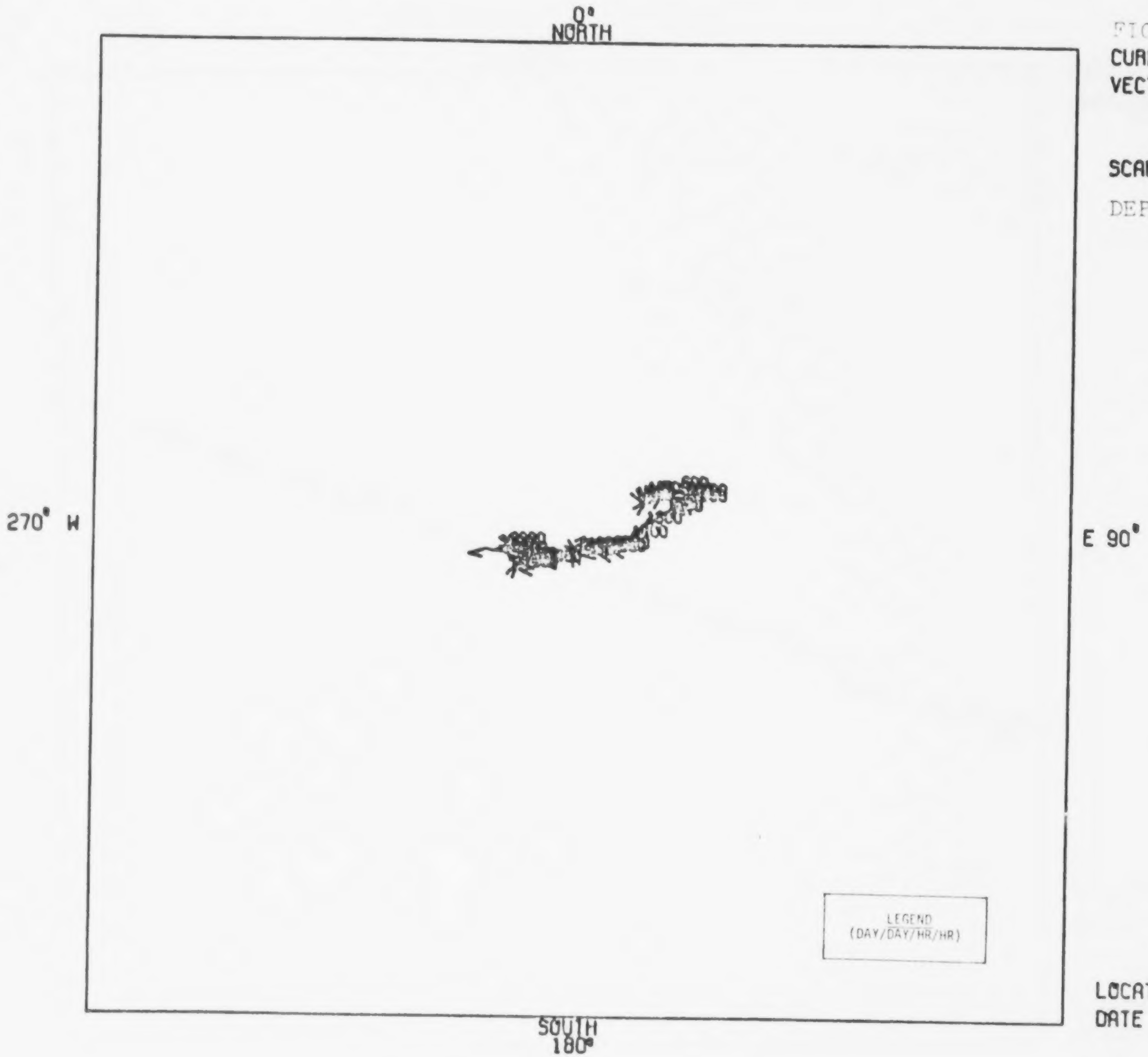
SCALE - 1 IN = 67562.00 M
DEPTH - 17.7m

LOCATION - BUCCANEER
DATE - 7608

FIGURE 81
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.0

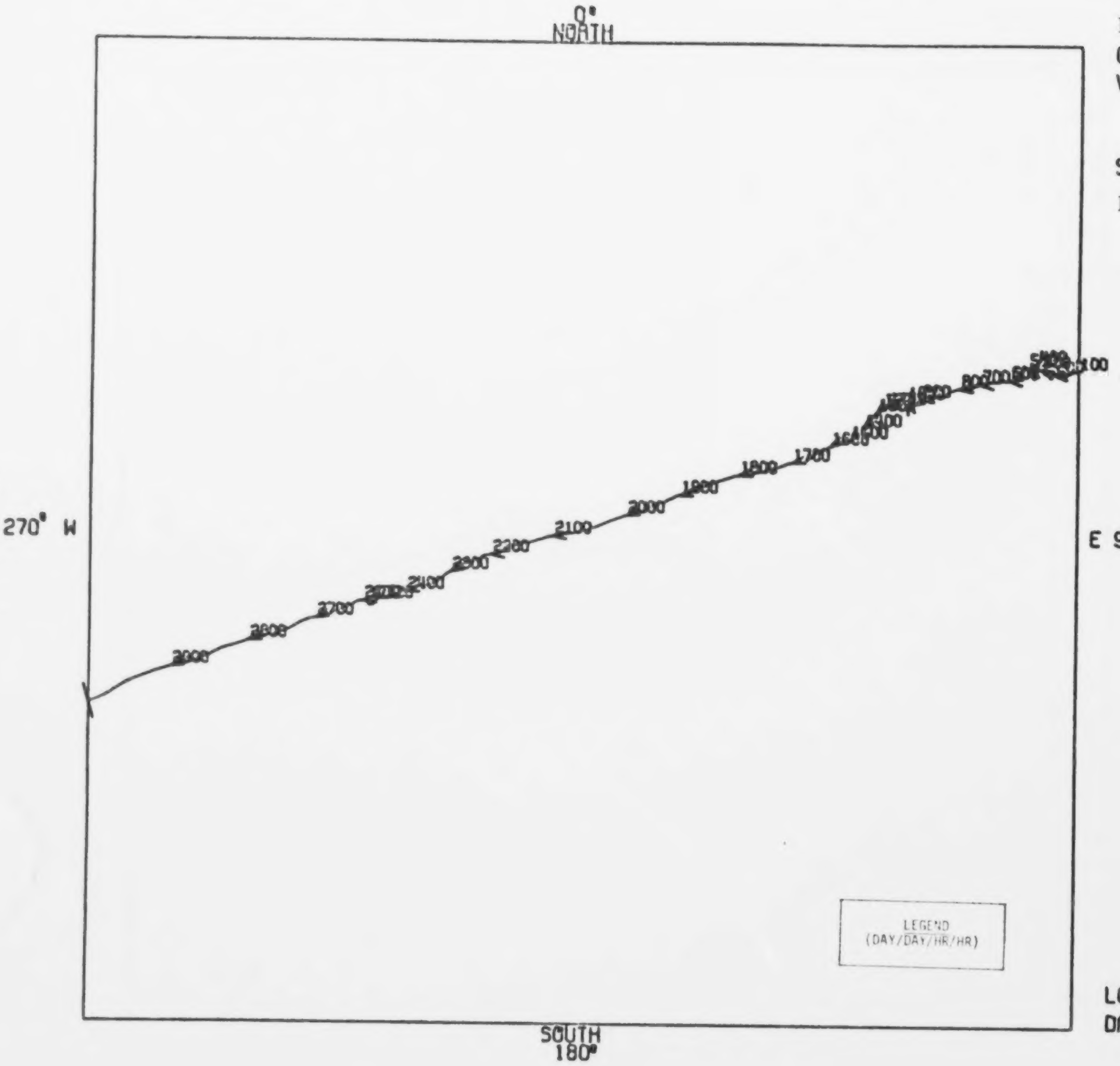
DEPTH - 17.7m



LOCATION - BUCCANEER
DATE - 7609

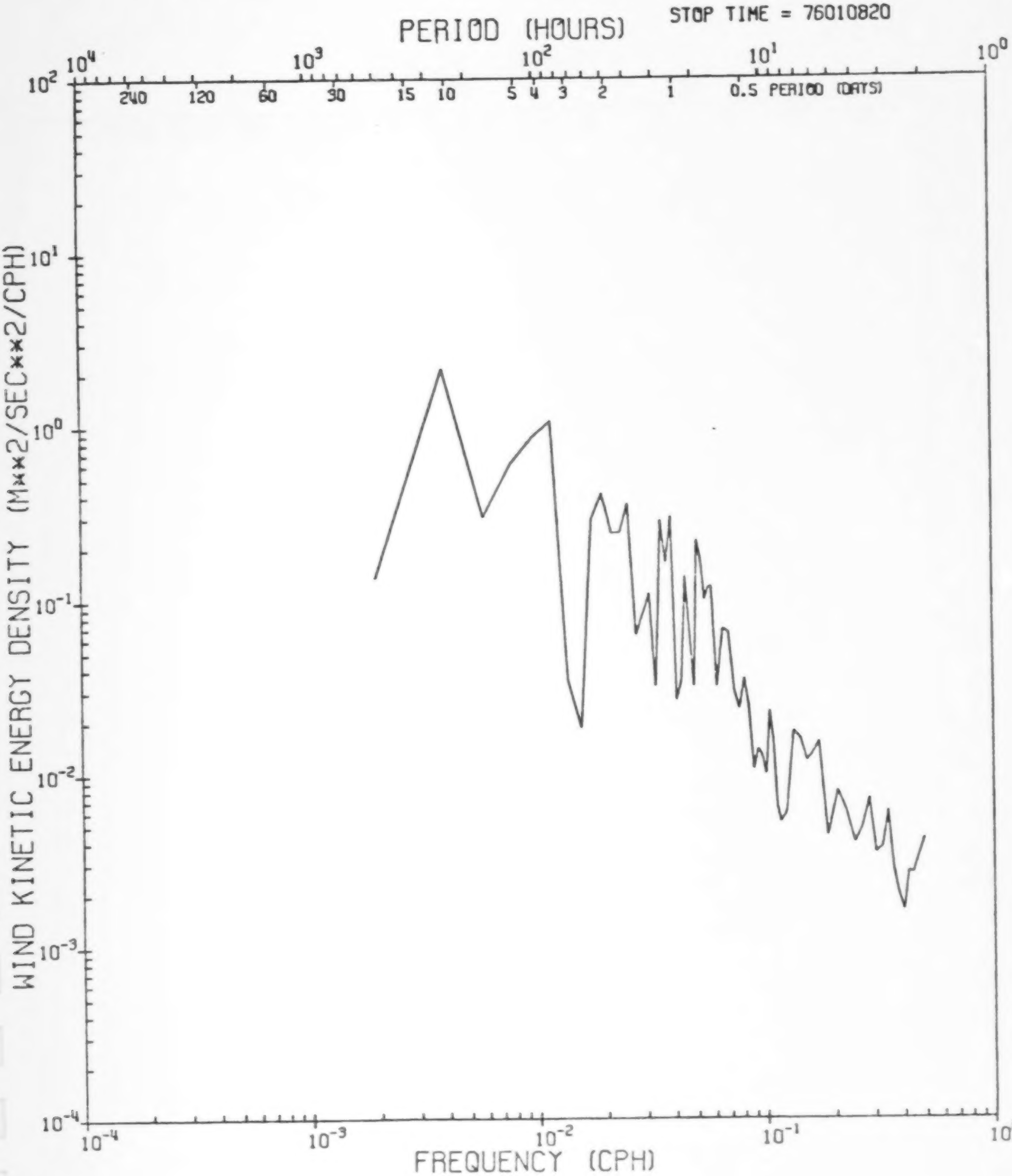
FIGURE 82
CURRENT PROGRESSIVE
VECTOR DIAGRAM

SCALE - 1 IN = 67562.00 M
DEPTH - 17.7m



LOCATION - BUCCANEER
DATE - 7610

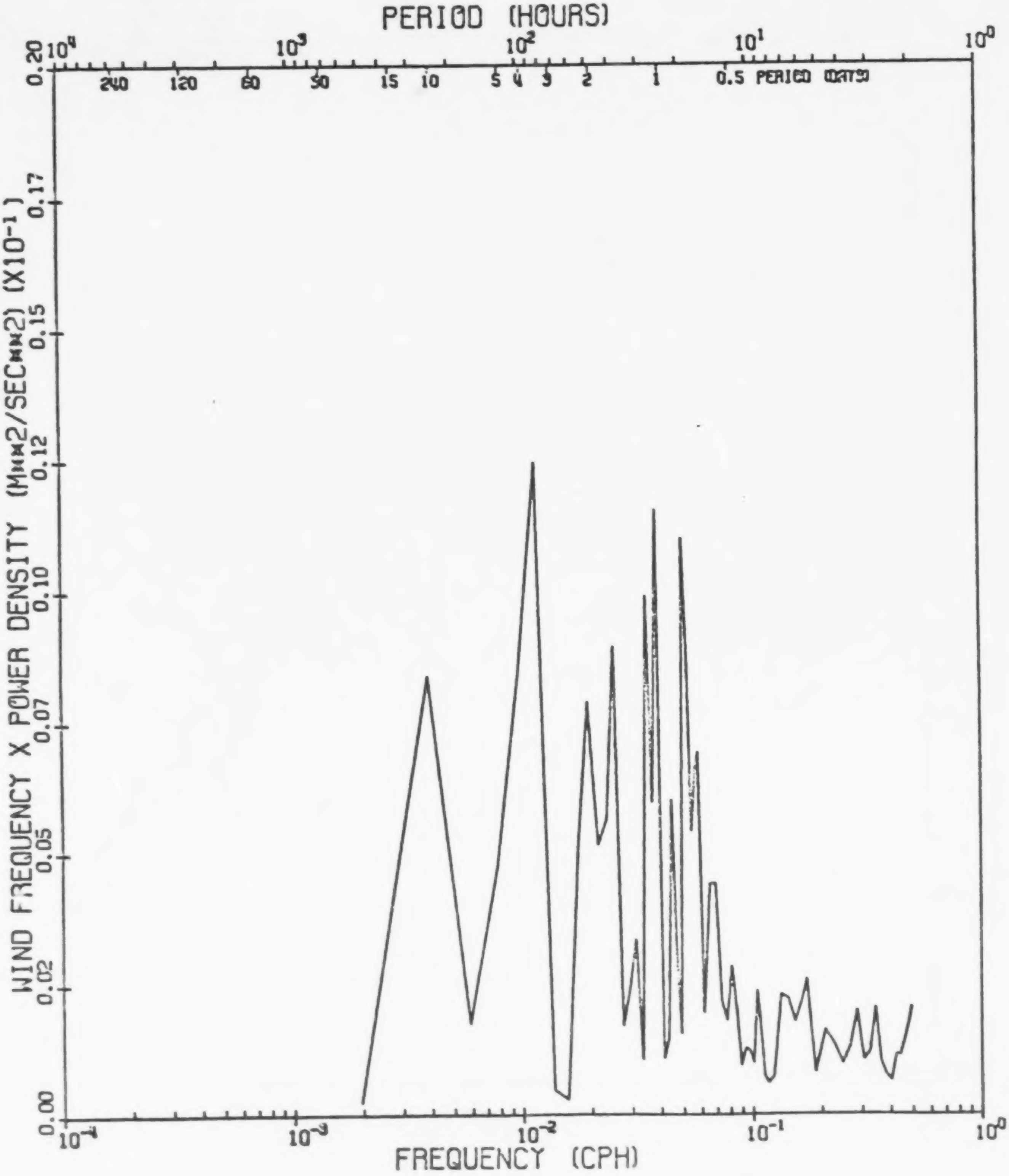
FIGURE 63



START TIME = 75121813

STOP TIME = 76010820

FIGURE 84
START TIME = 75121813
STOP TIME = 7601020



START TIME = 76012011
STOP TIME = 76013102

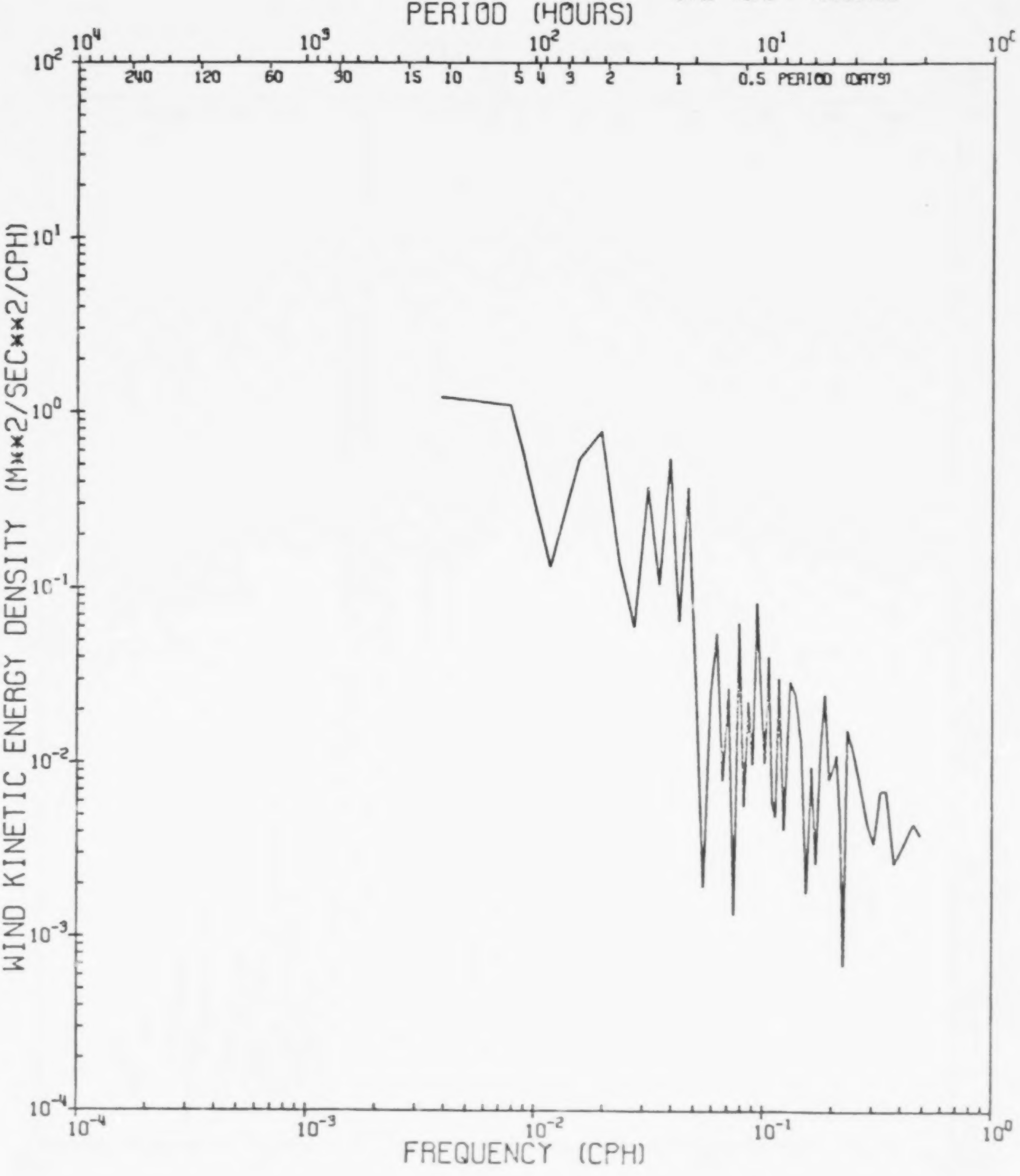


FIGURE 85
START TIME = 76012011
STOP TIME = 76013102

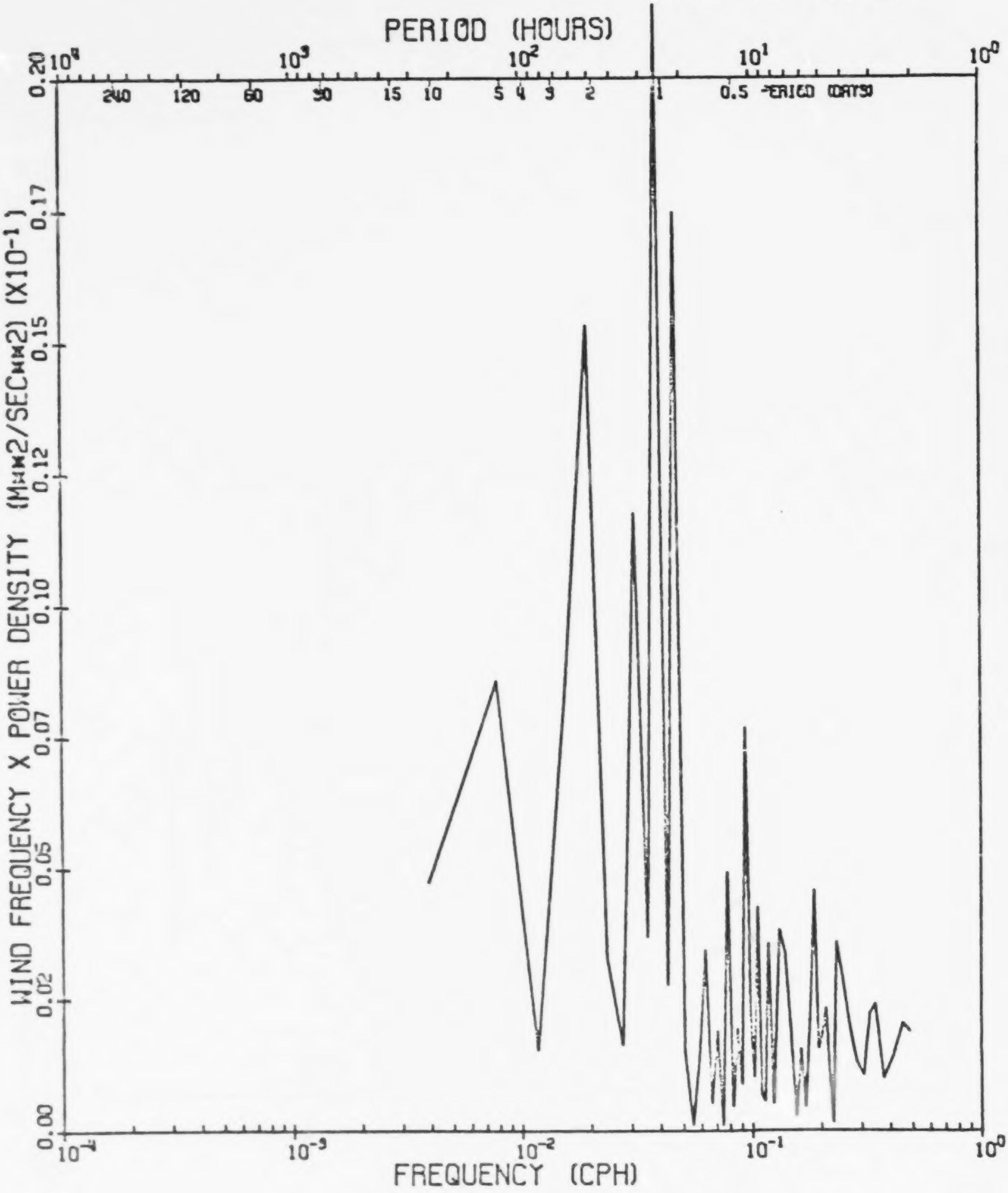


FIGURE 87

START TIME = 76021311

STOP TIME = 76050818

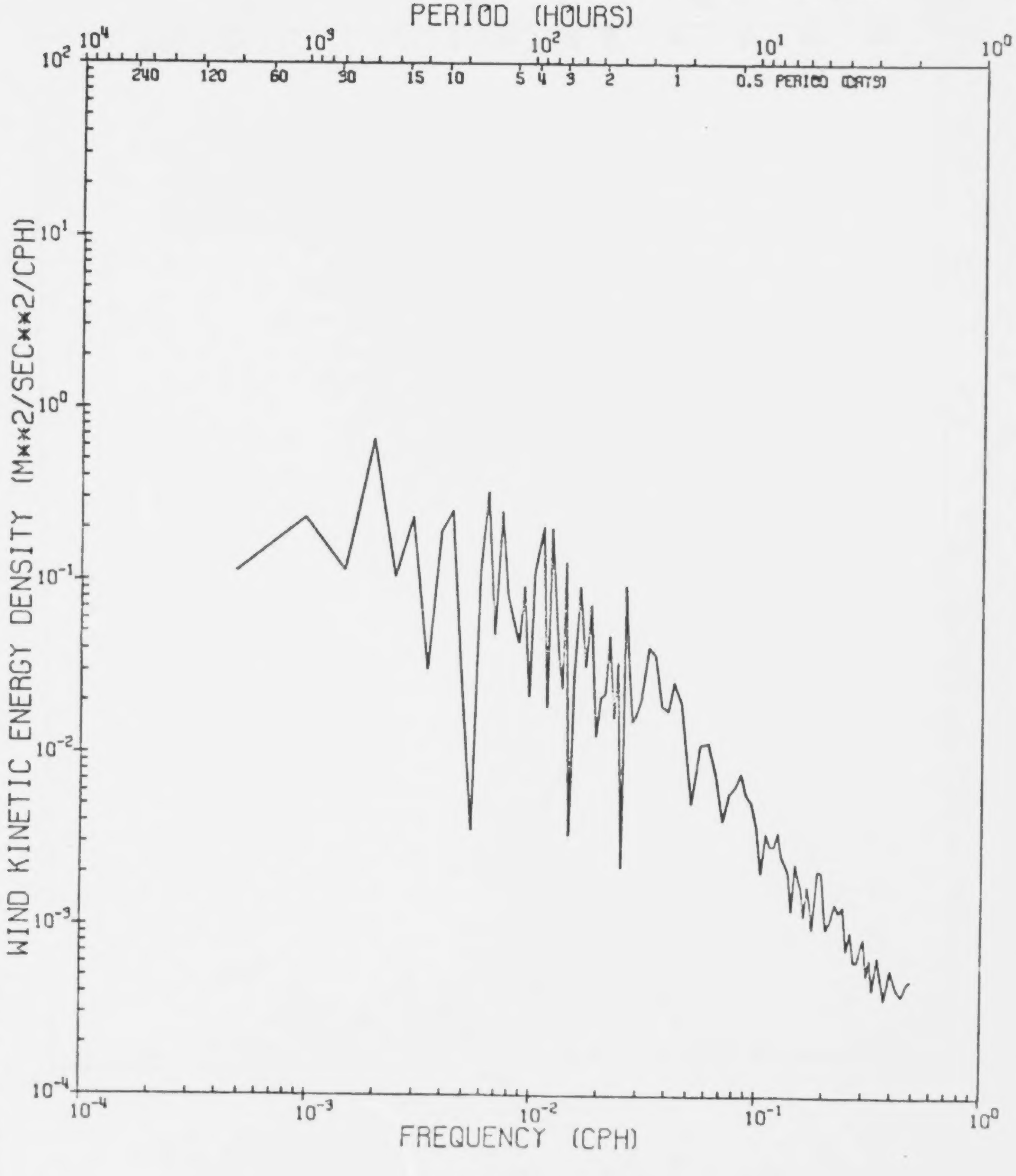


FIGURE 88
START TIME = 76021311
STOP TIME = 76050818

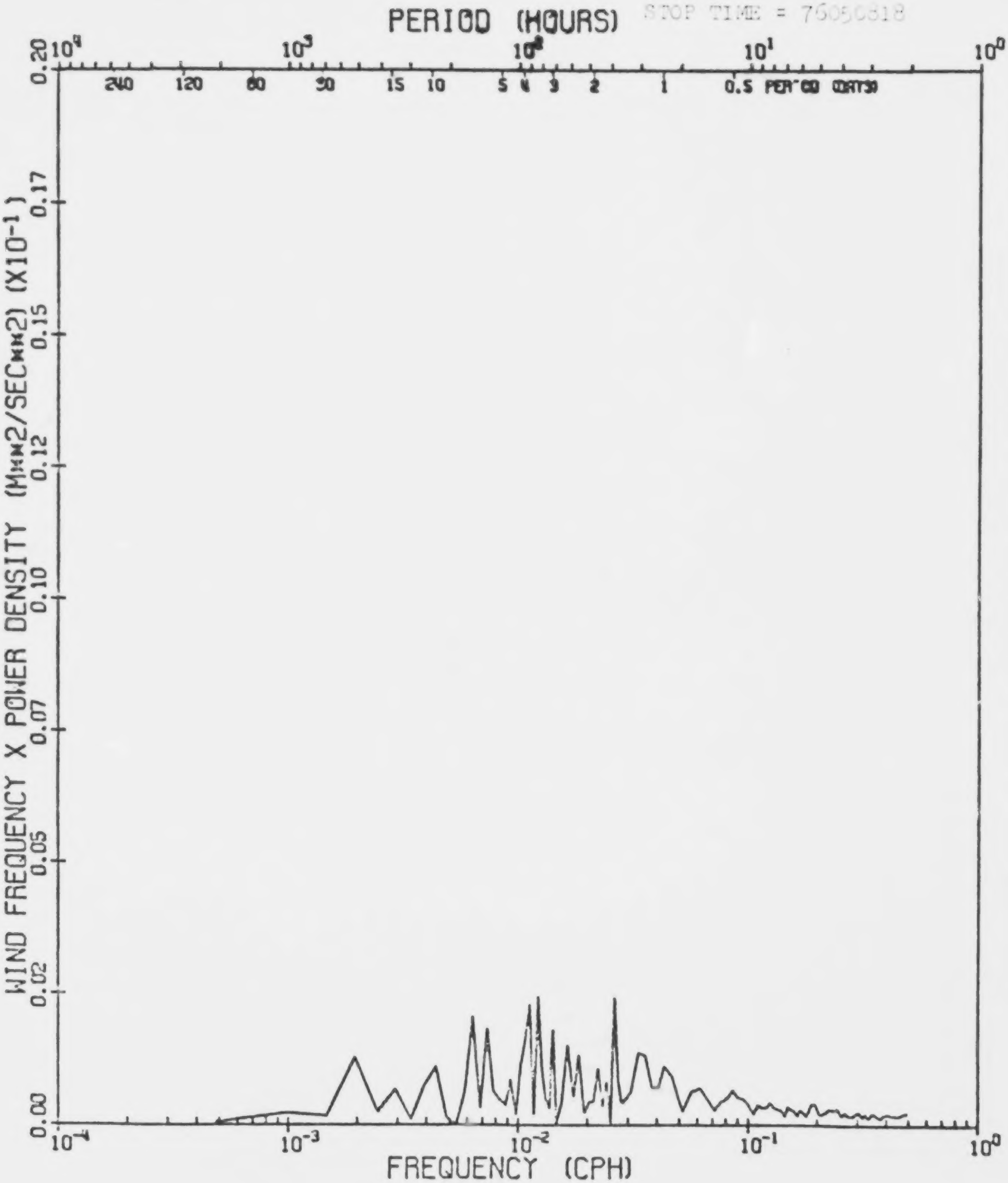


FIGURE 89

START TIME = 76051709

STOP TIME = 76062900

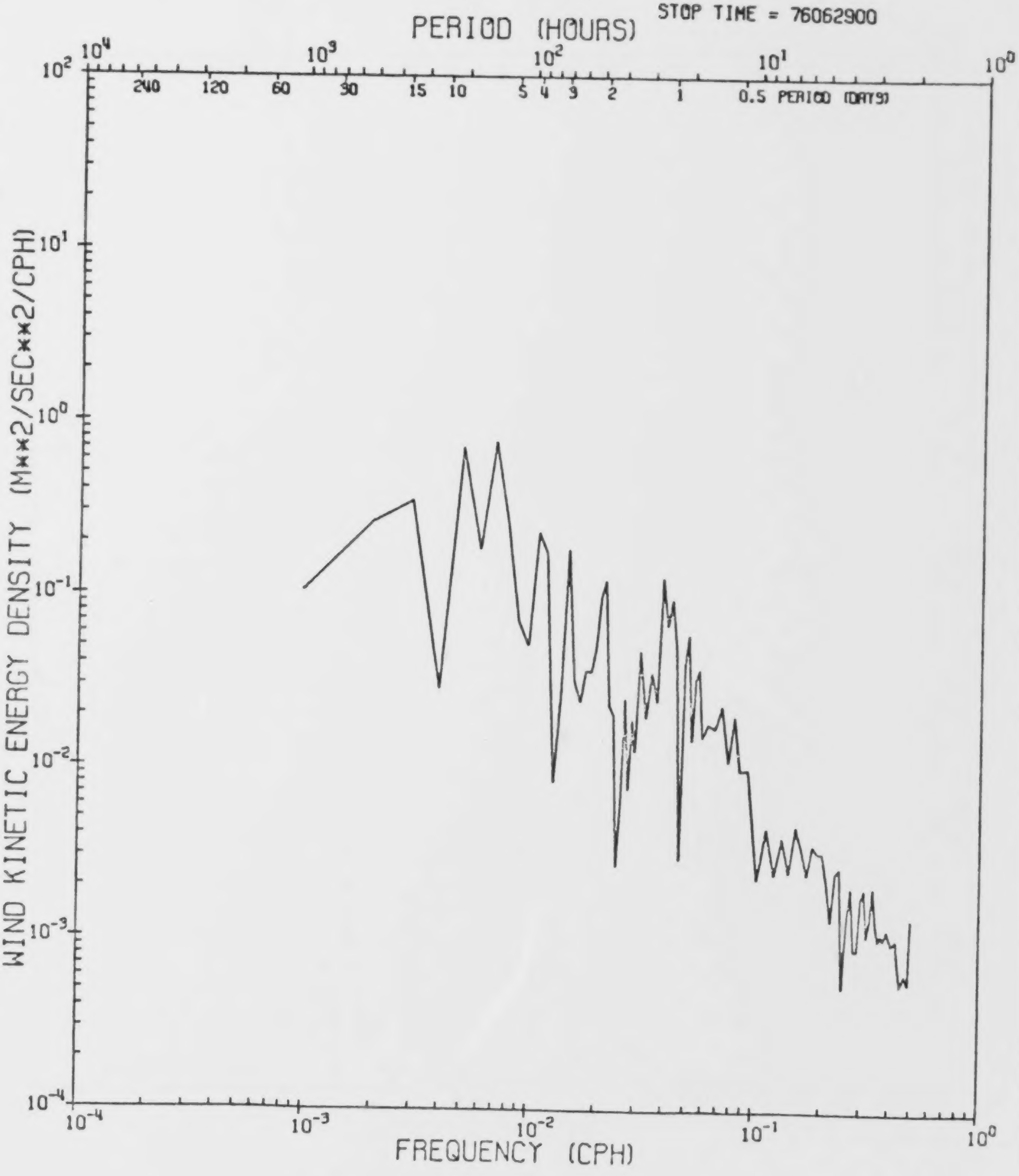


FIGURE 90
START TIME = 76051709
STOP TIME = 76062900

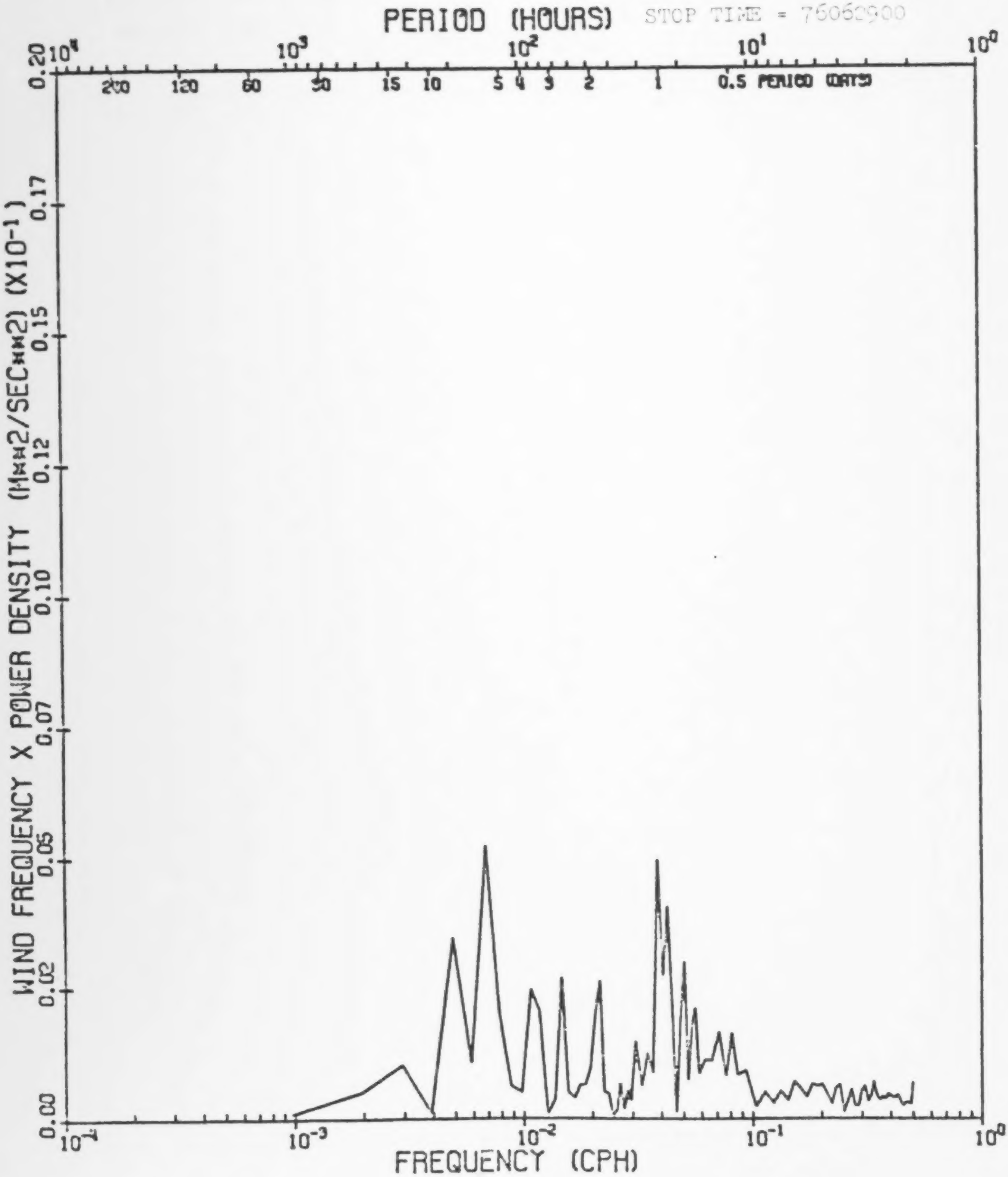


FIGURE [illegible]

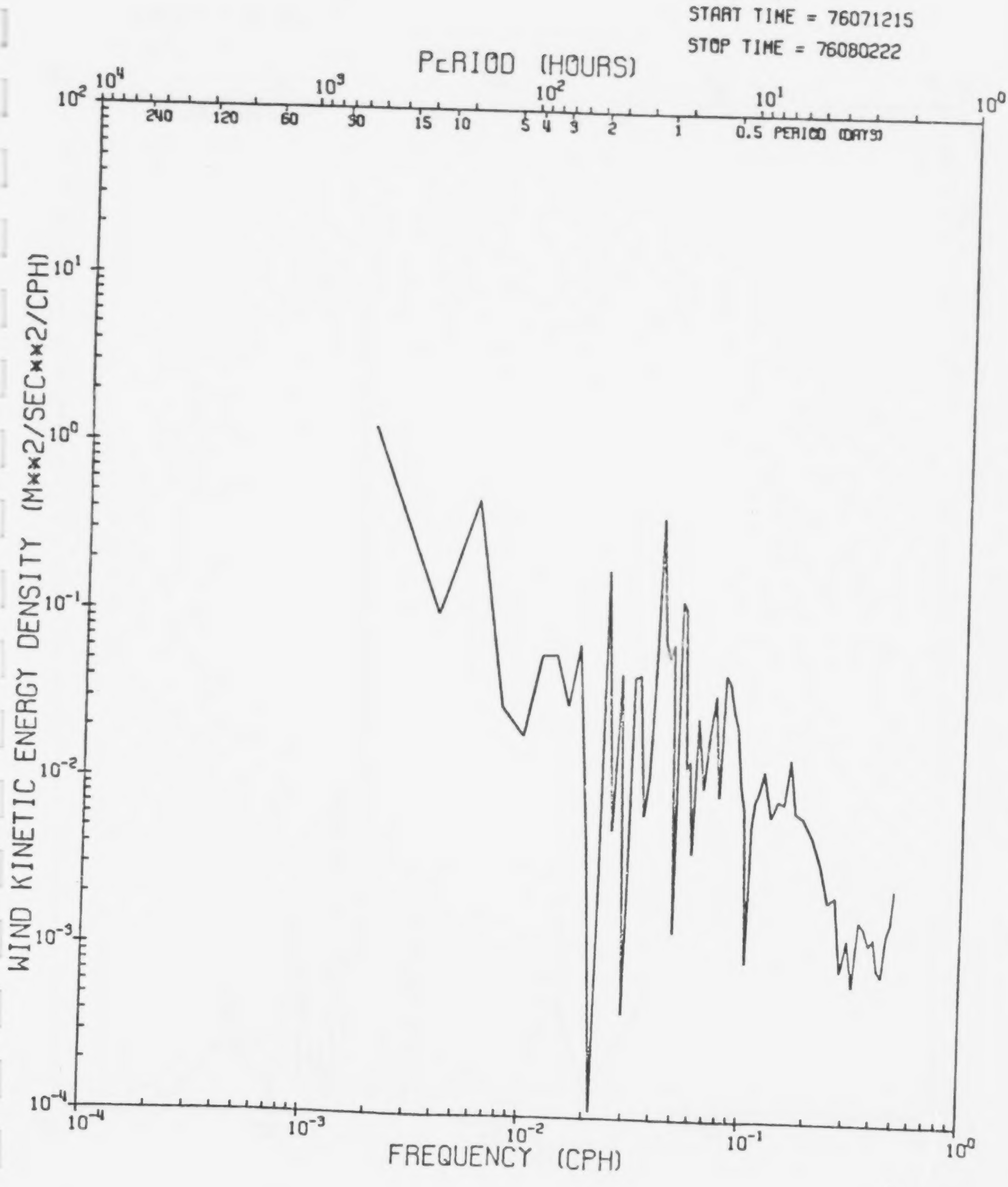

START TIME = 76071215
STOP TIME = 76080222
PERIOD (HOURS)
10^4
10^3
10^2
10^1
10^0
240
120
60
30
15
10
5
4
3
2
1
0.5 PERIOD (DAYS)
WIND KINETIC ENERGY DENSITY (M**2/SEC**2/CPH)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
FREQUENCY (CPH)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0

FIGURE 92
START TIME = 76071215
STOP TIME = 76080222

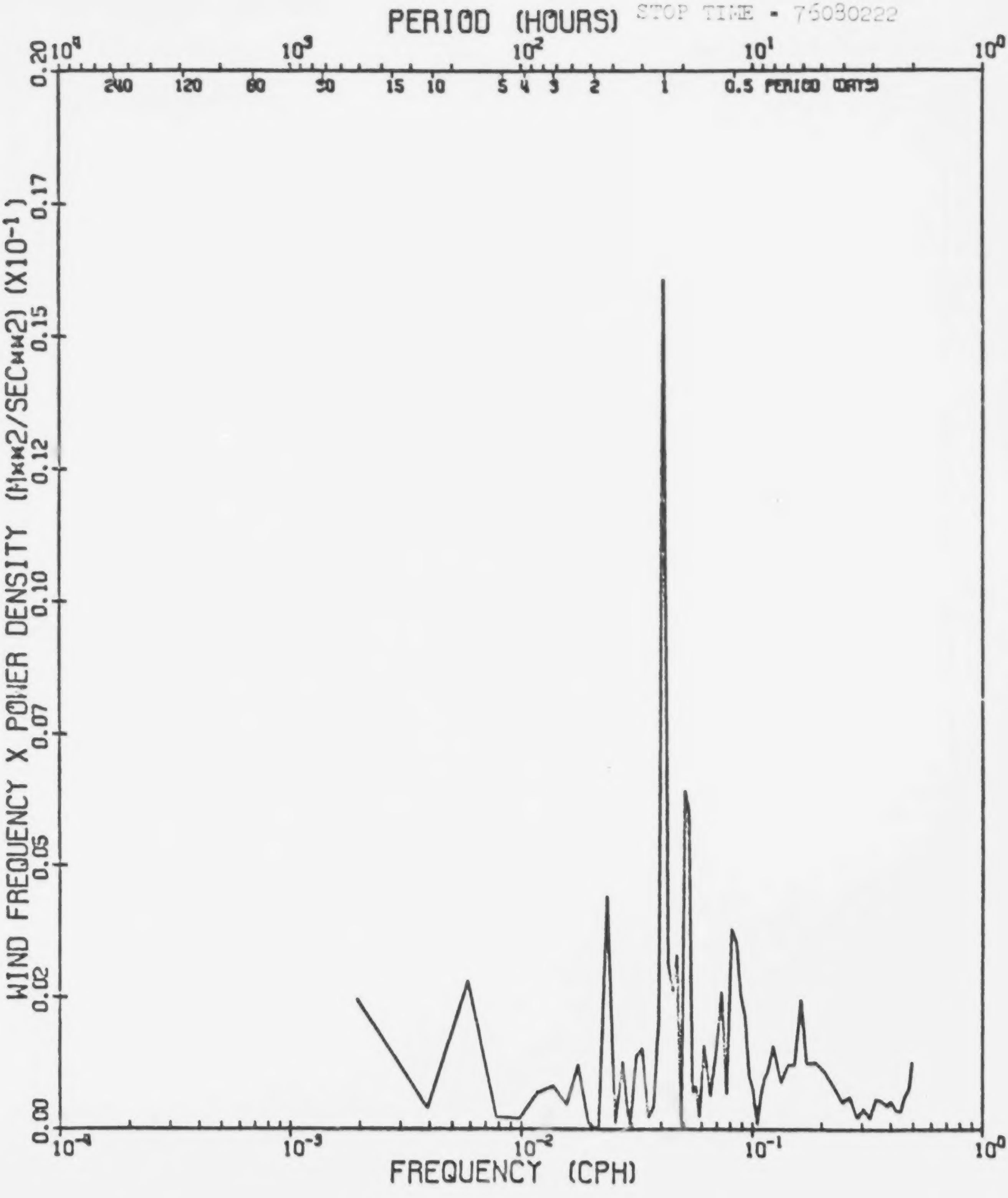


FIGURE 93

START TIME = 76081313

STOP TIME = 76110620

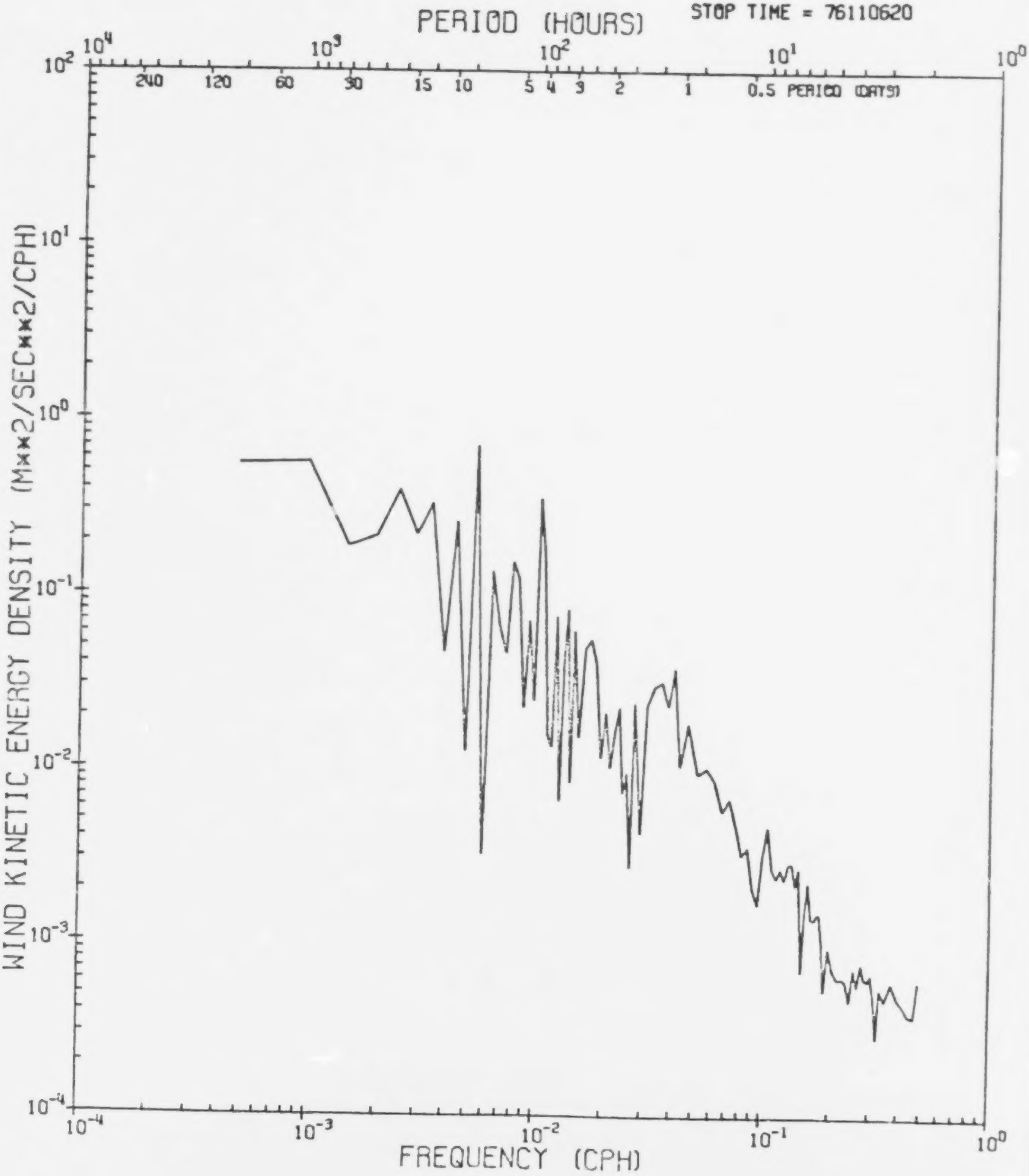


FIGURE 94
START TIME = 76081313
STOP TIME - 76110620

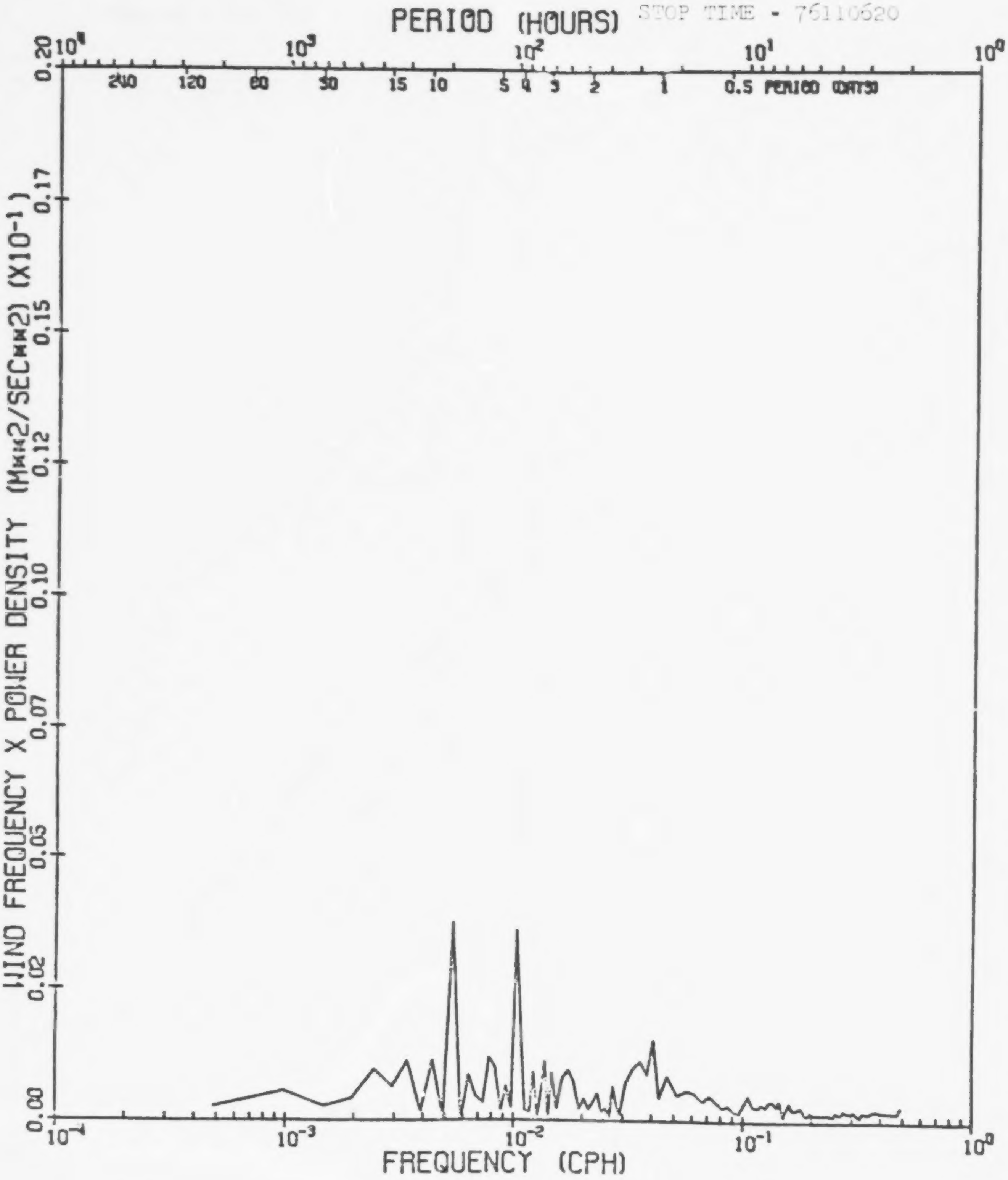


FIGURE [illegible]

START TIME = 76112911

STOP TIME = 76122018

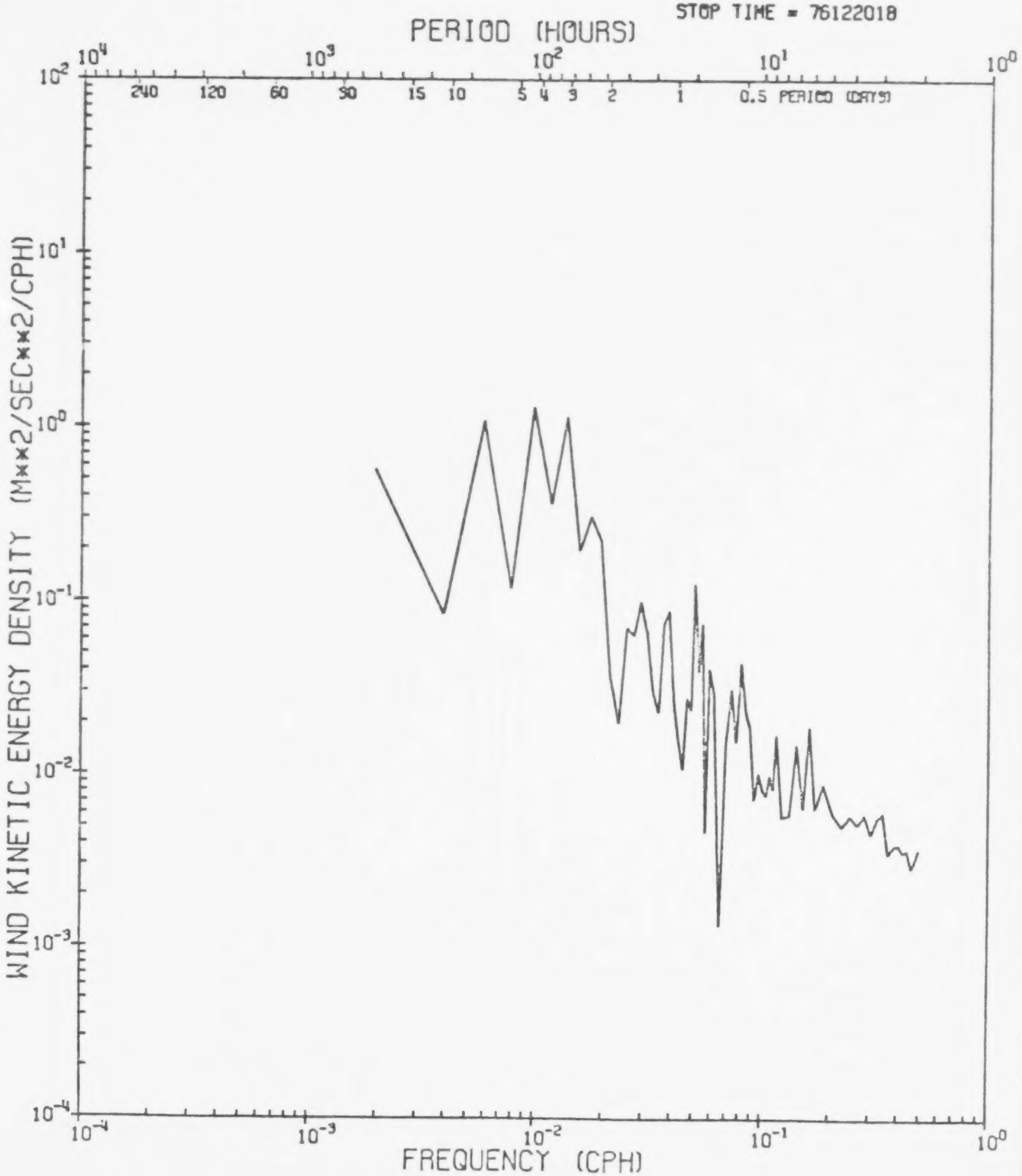


FIGURE 96
START TIME = 76112911
STOP TIME = 76122018

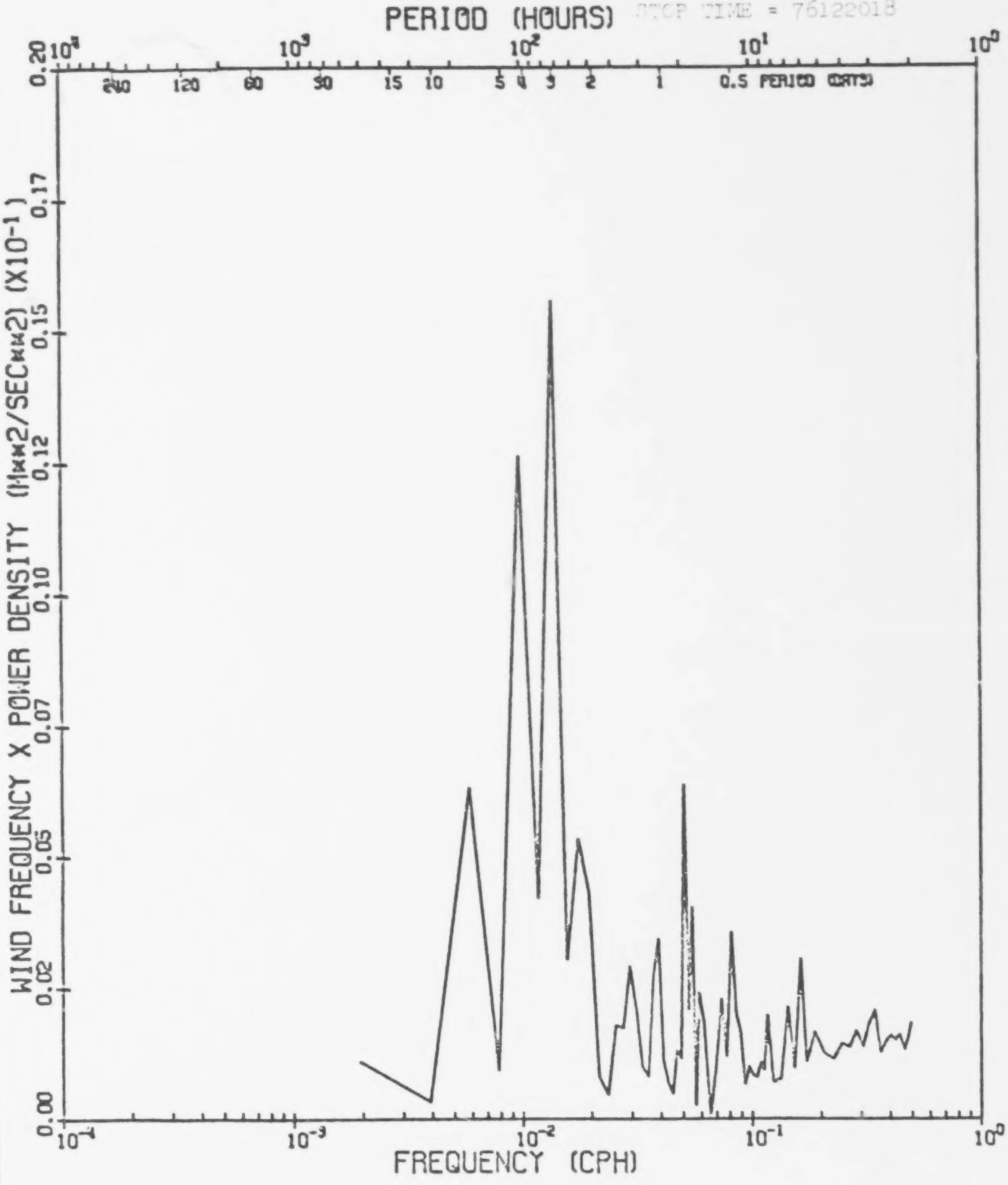


FIGURE 97

START TIME = 76032314

STOP TIME = 76041321

SURFACE

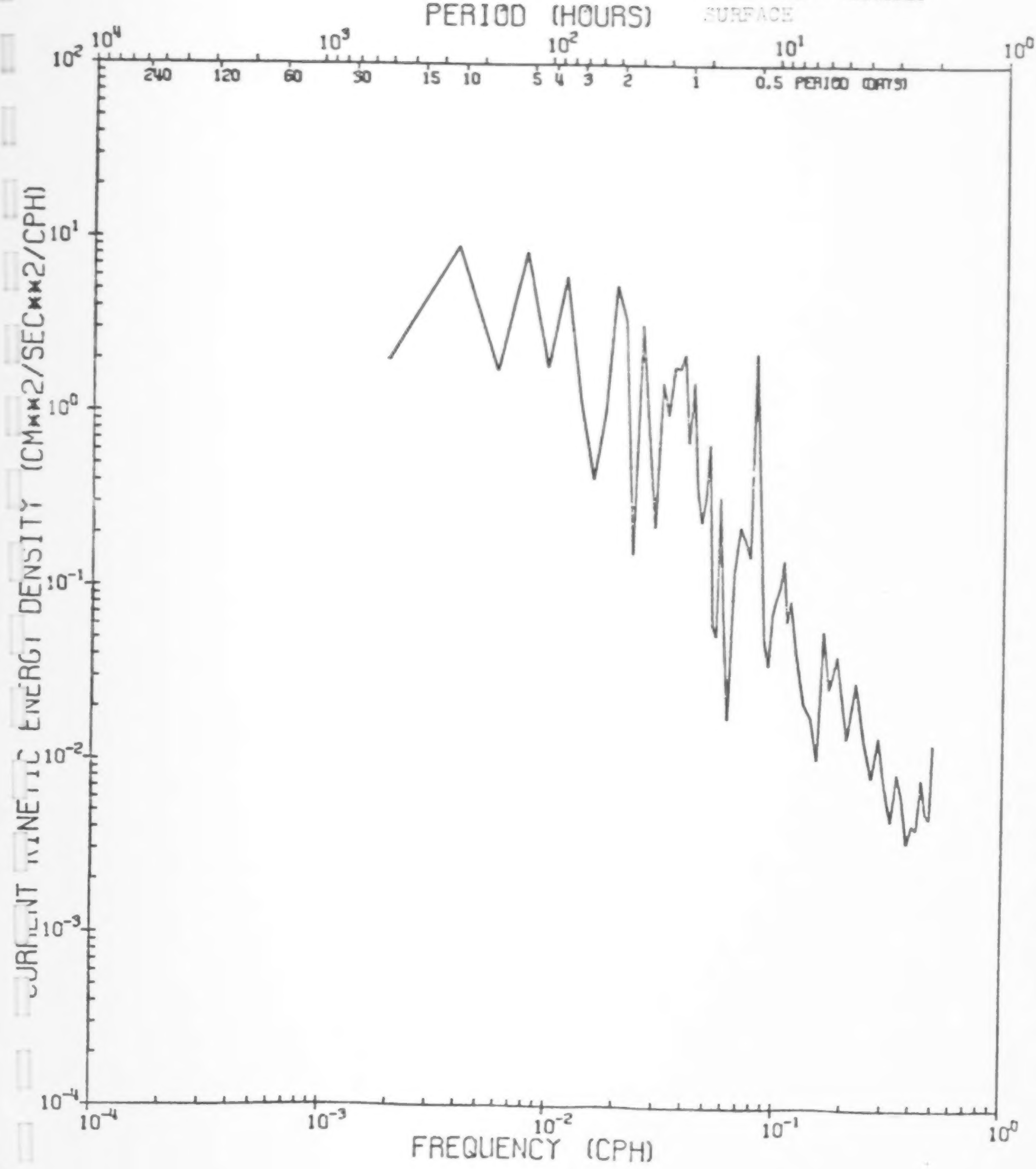


FIGURE [illegible]

START TIME = 76032314

STOP TIME = 76041321

SURFACE

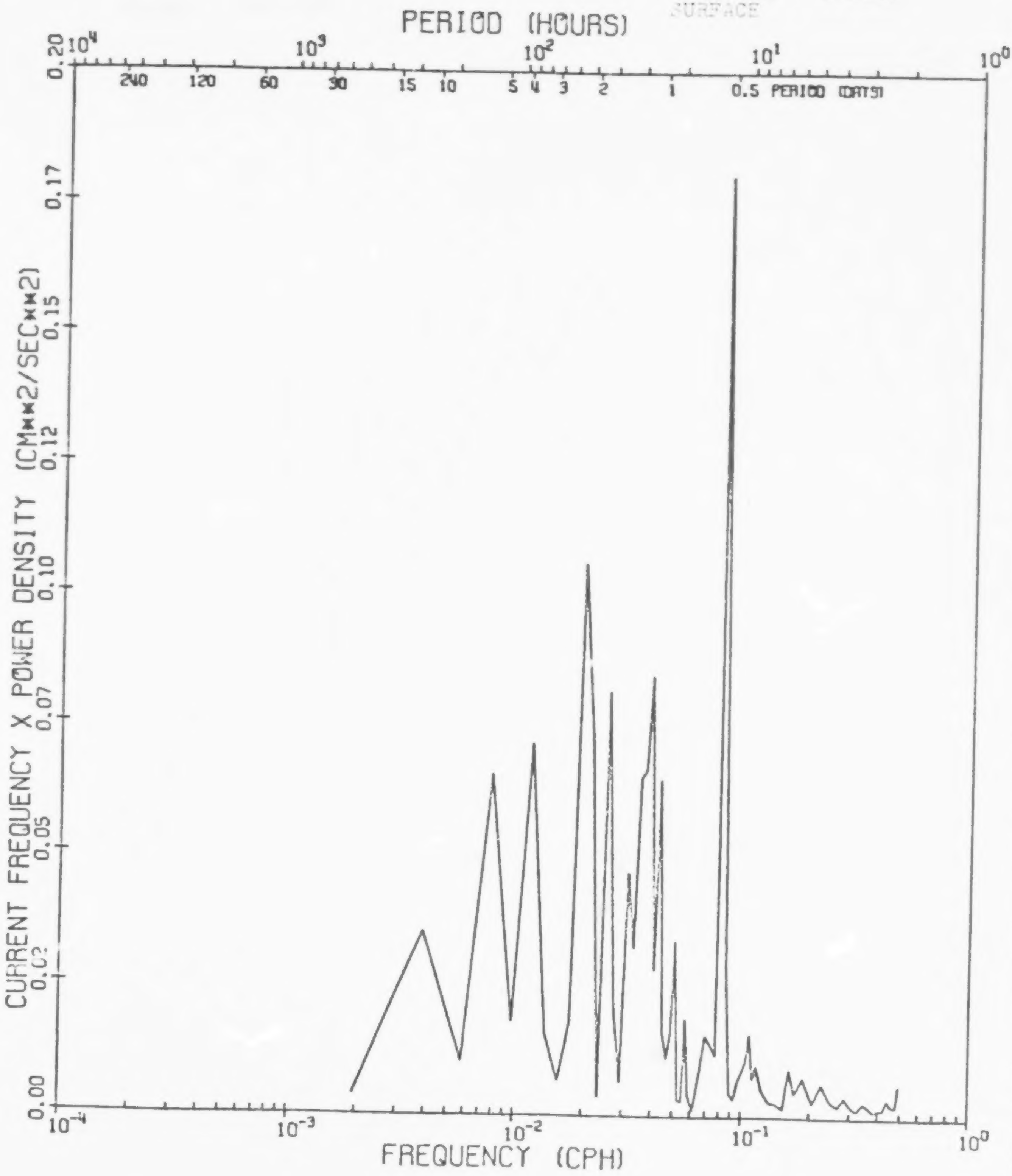


FIGURE 66

START TIME = 76061011

STOP TIME = 76112802

SURFACE

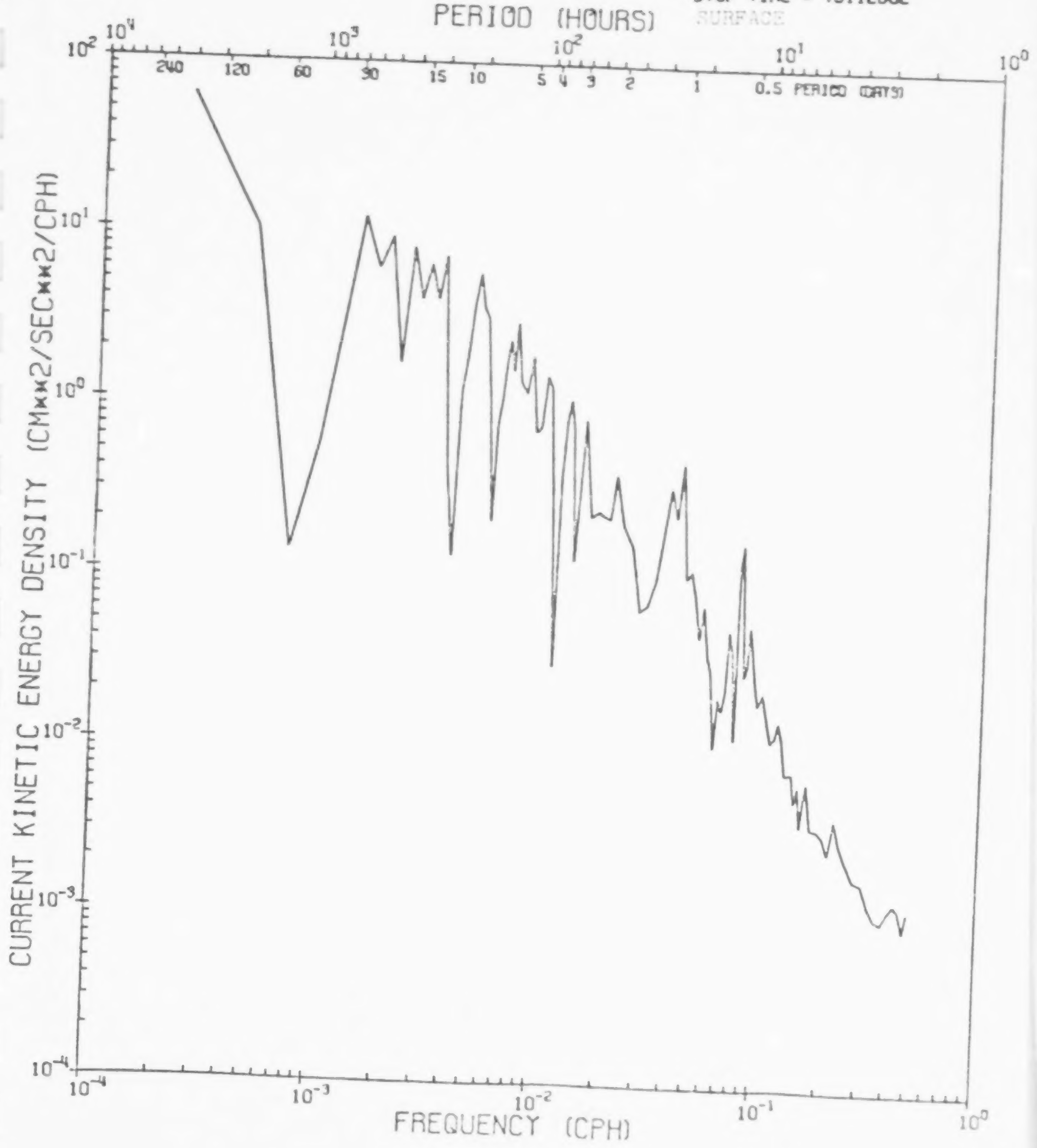


FIGURE 100

START TIME = 76061011

STOP TIME = 76112802

SURFACE

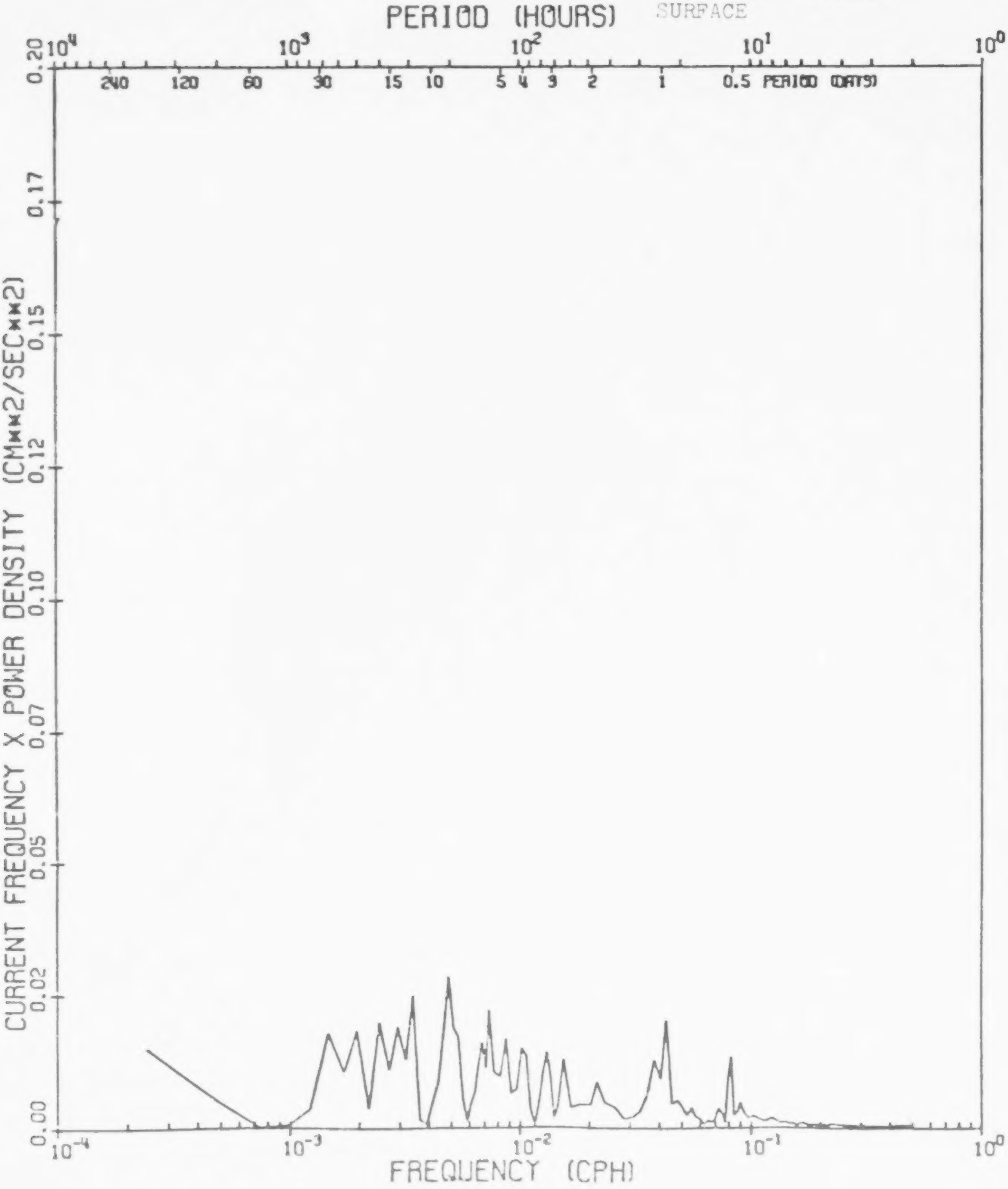


FIGURE 101

START TIME = 75121812

STOP TIME = 75122903

DEPTH -10.0m

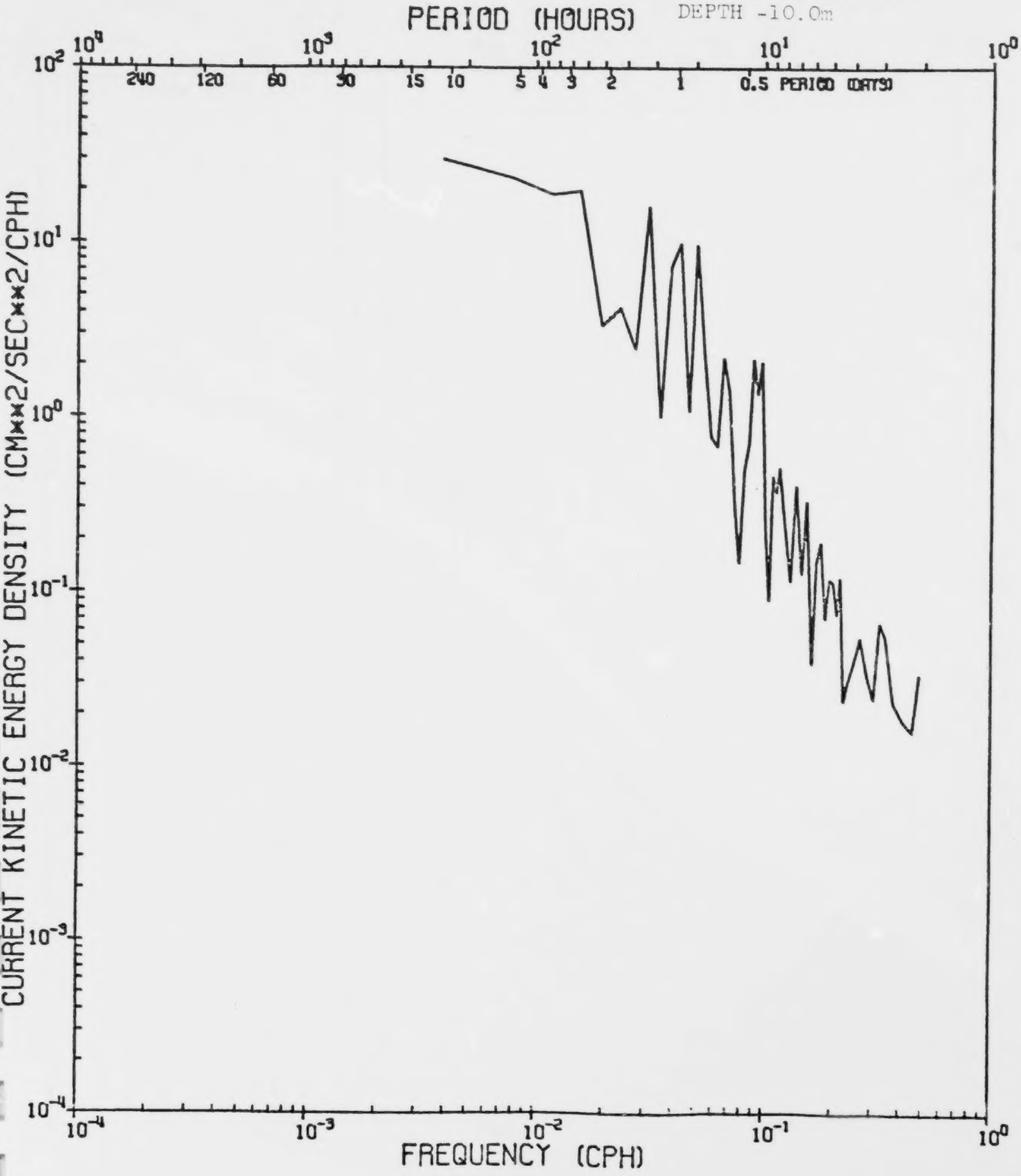


FIGURE 102

START TIME = 75121812

STOP TIME = 75122903

DEPTH - 10.0m

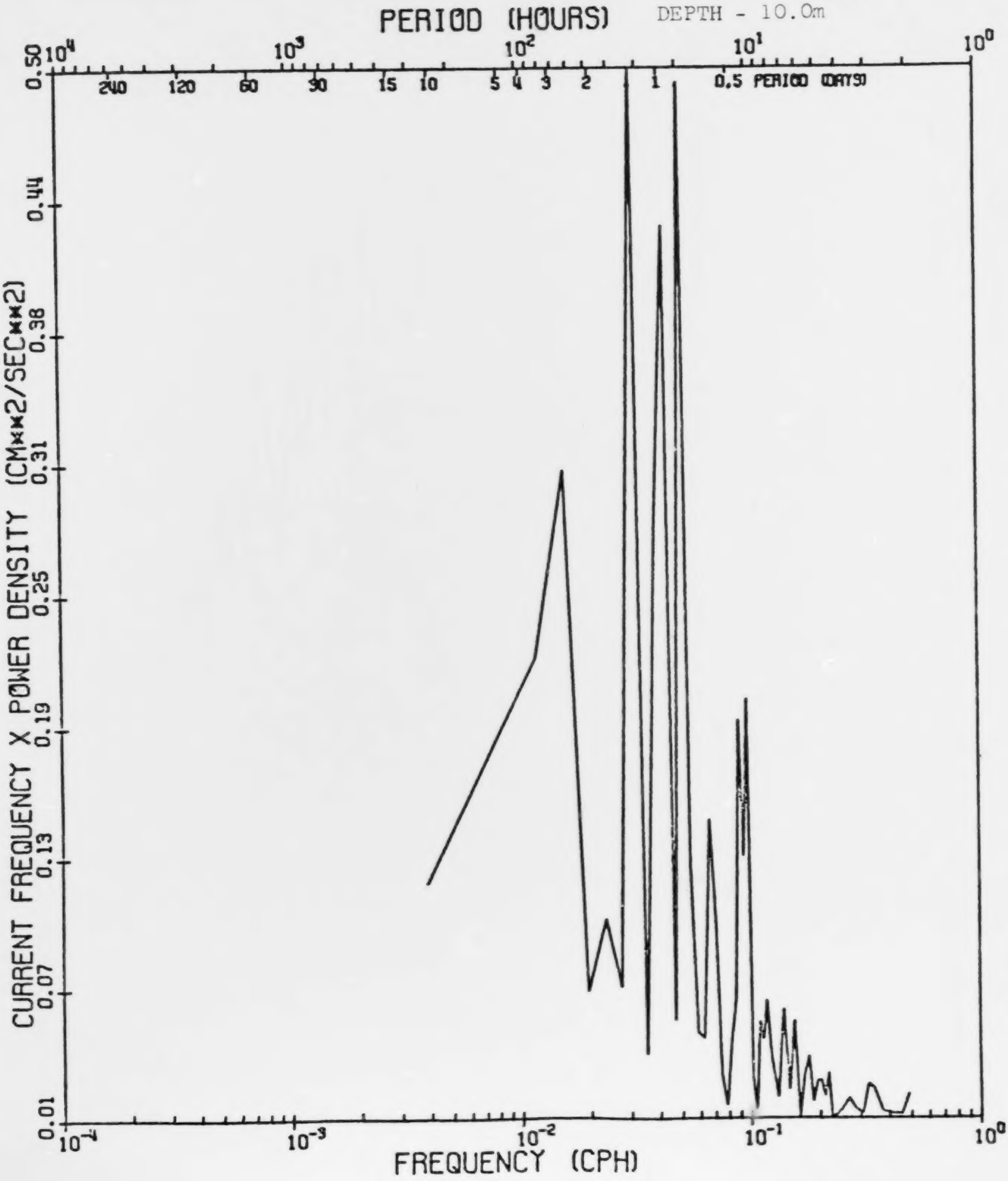


FIGURE 103

START TIME = 76011611

STOP TIME = 76022802

DEPTH -10.0m

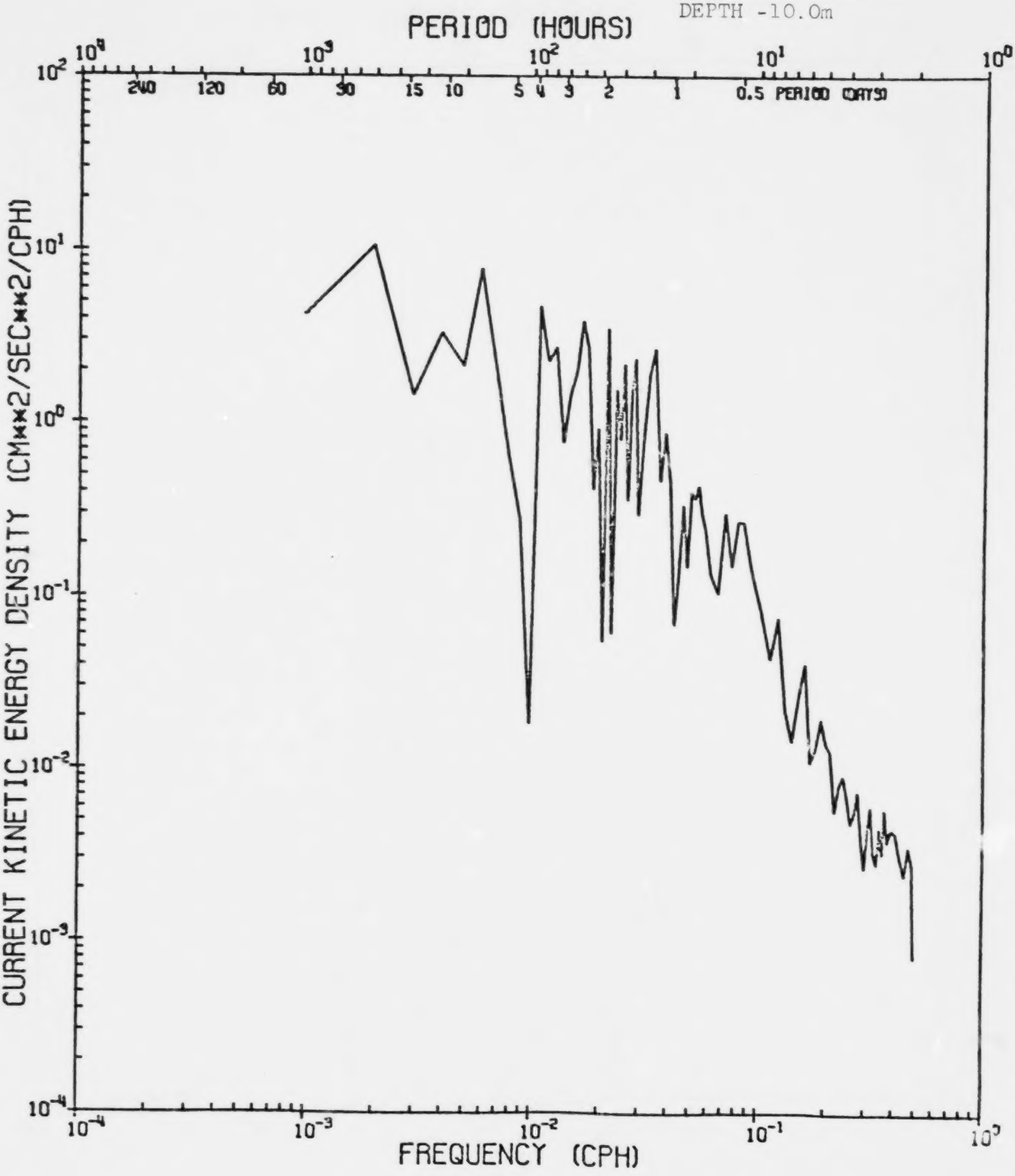


FIGURE 104

START TIME = 76011611

STOP TIME = 76022802

DEPTH - 10.0m

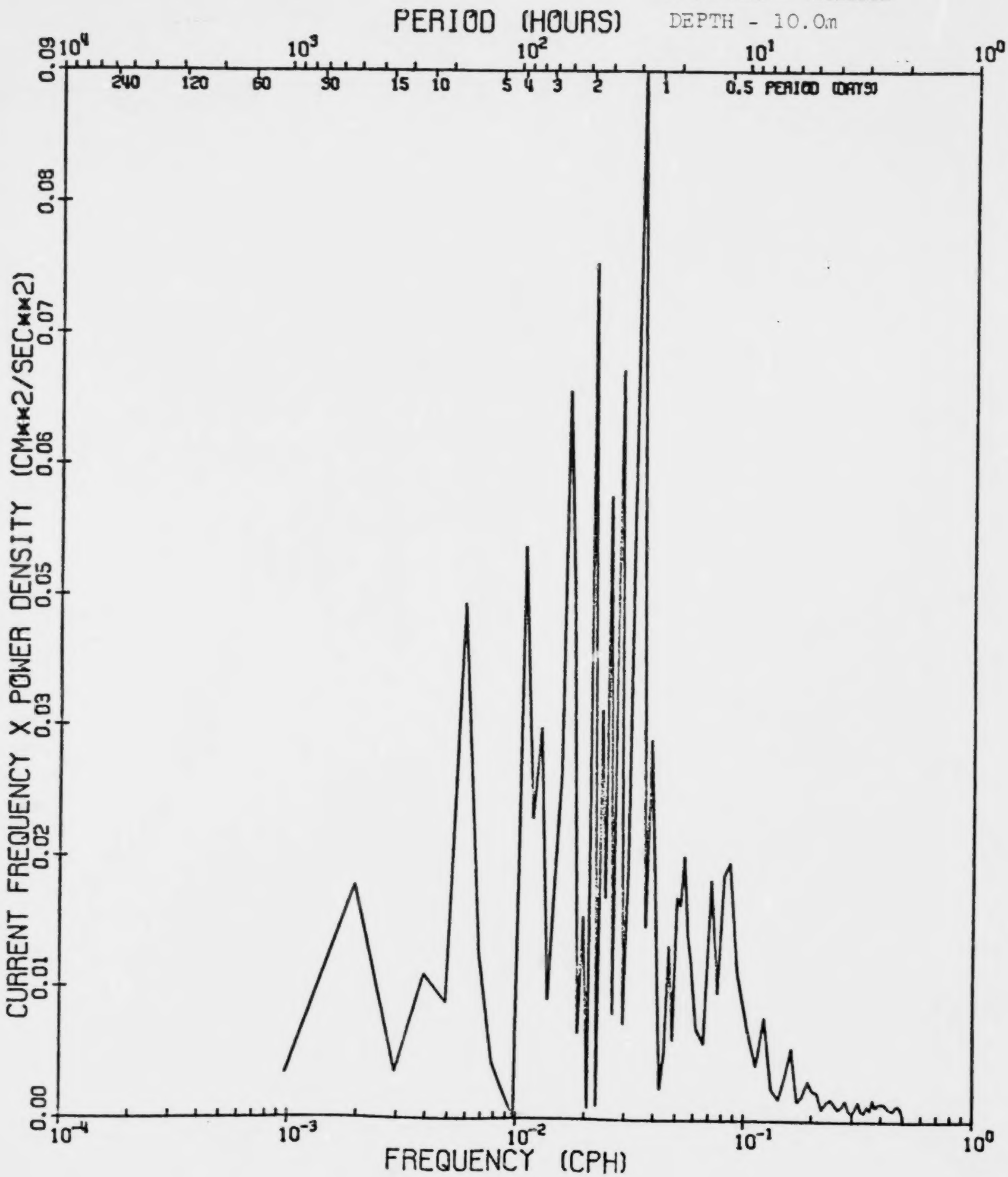


FIGURE 105

START TIME = 76032314

STOP TIME = 76041321

DEPTH -10.0m

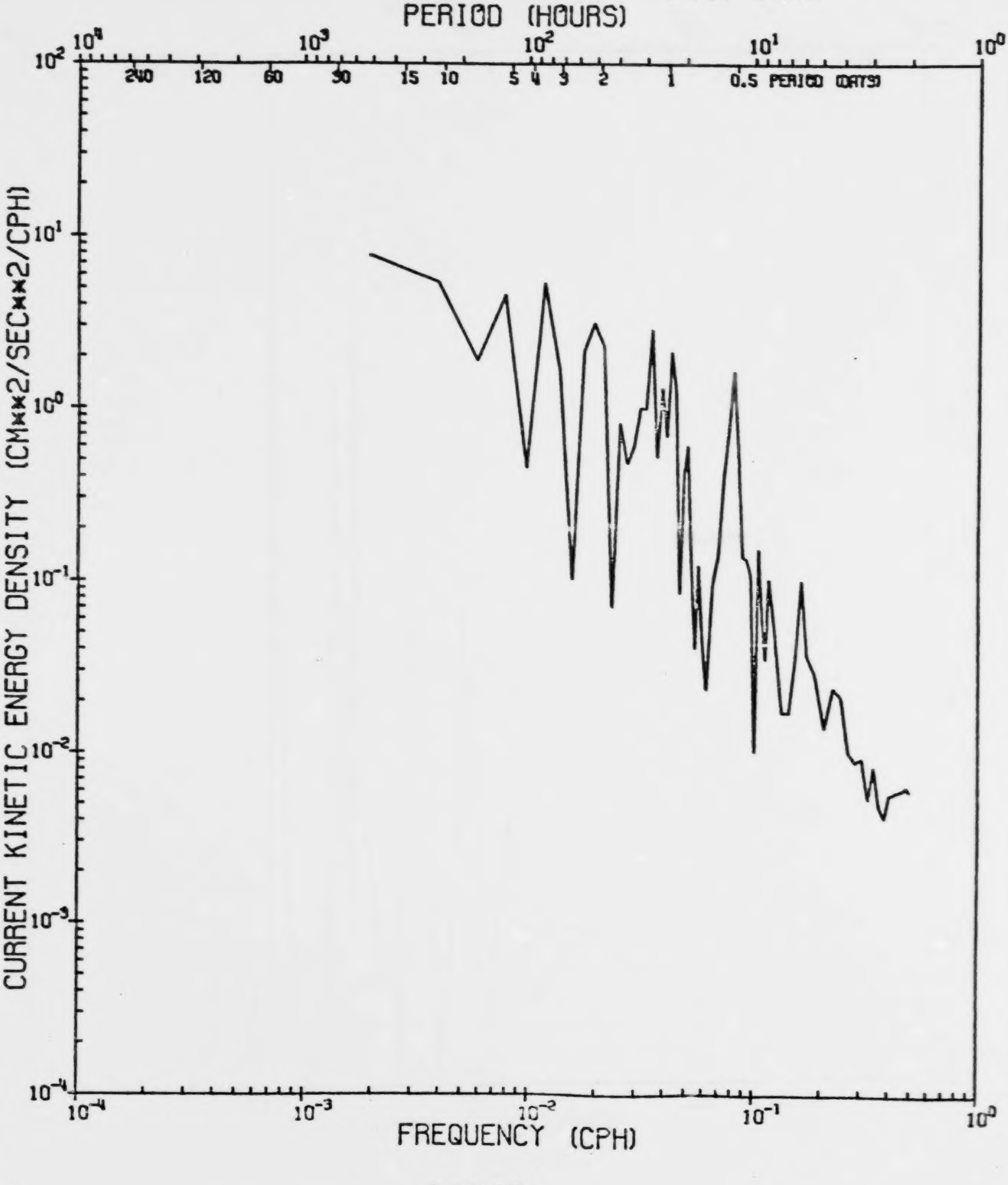


FIGURE 106

START TIME = 76032314

STOP TIME = 76041321

DEPTH - 10.0m

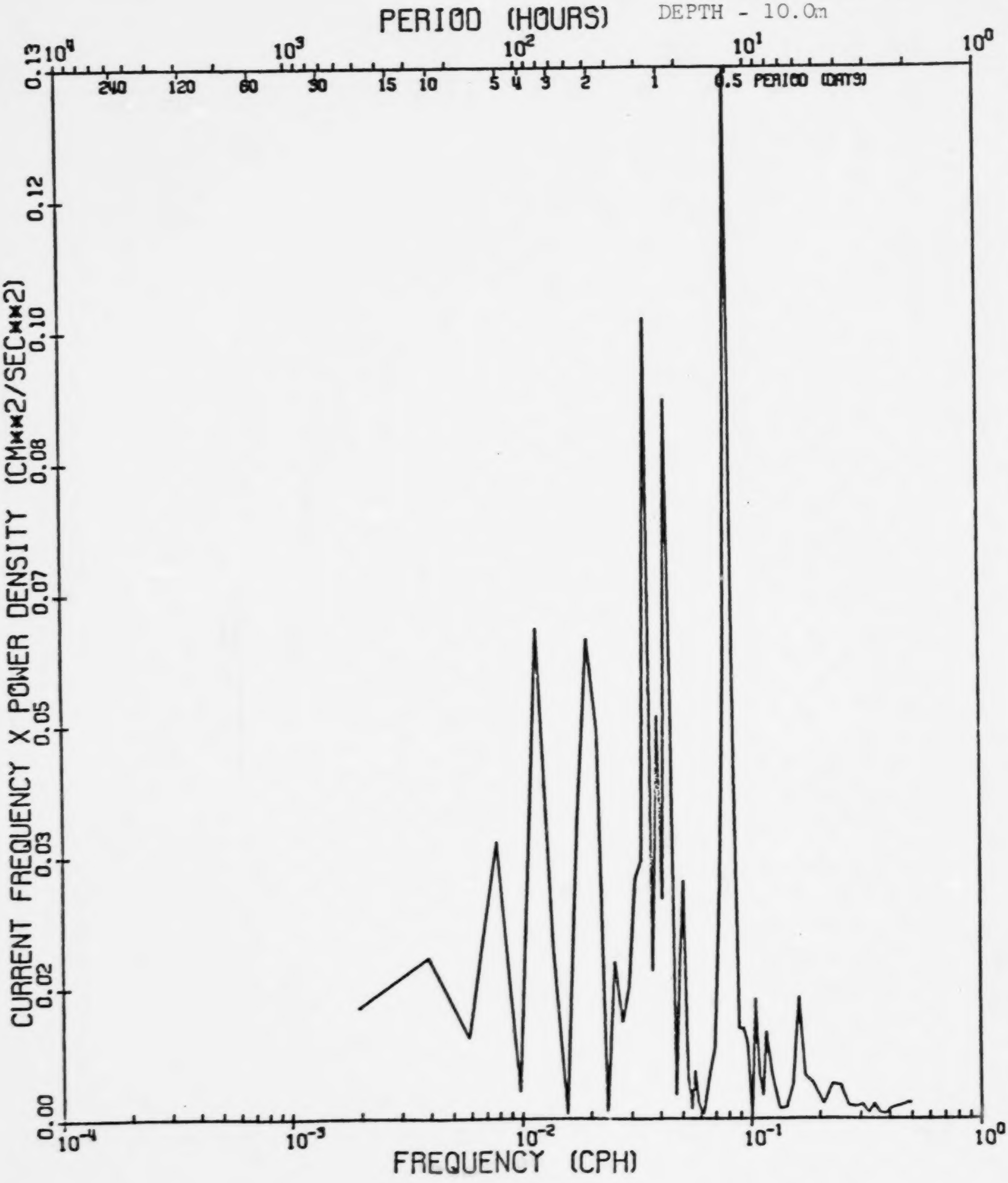


FIGURE 107

START TIME = 76041418

STOP TIME = 76041709

DEPTH -10.0m

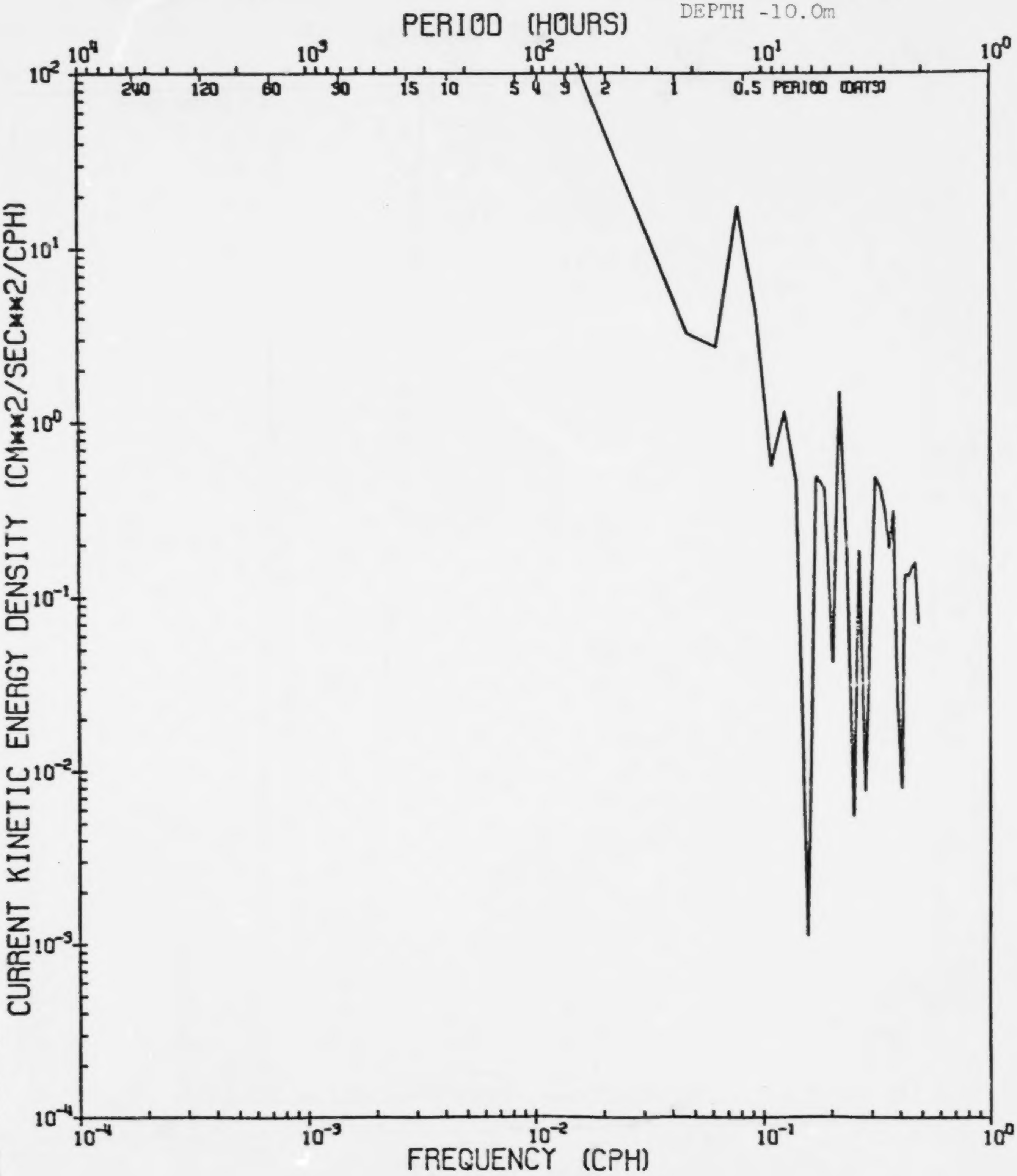


FIGURE 108

START TIME = 76041418

STOP TIME = 76041709

DEPTH - 10.0m

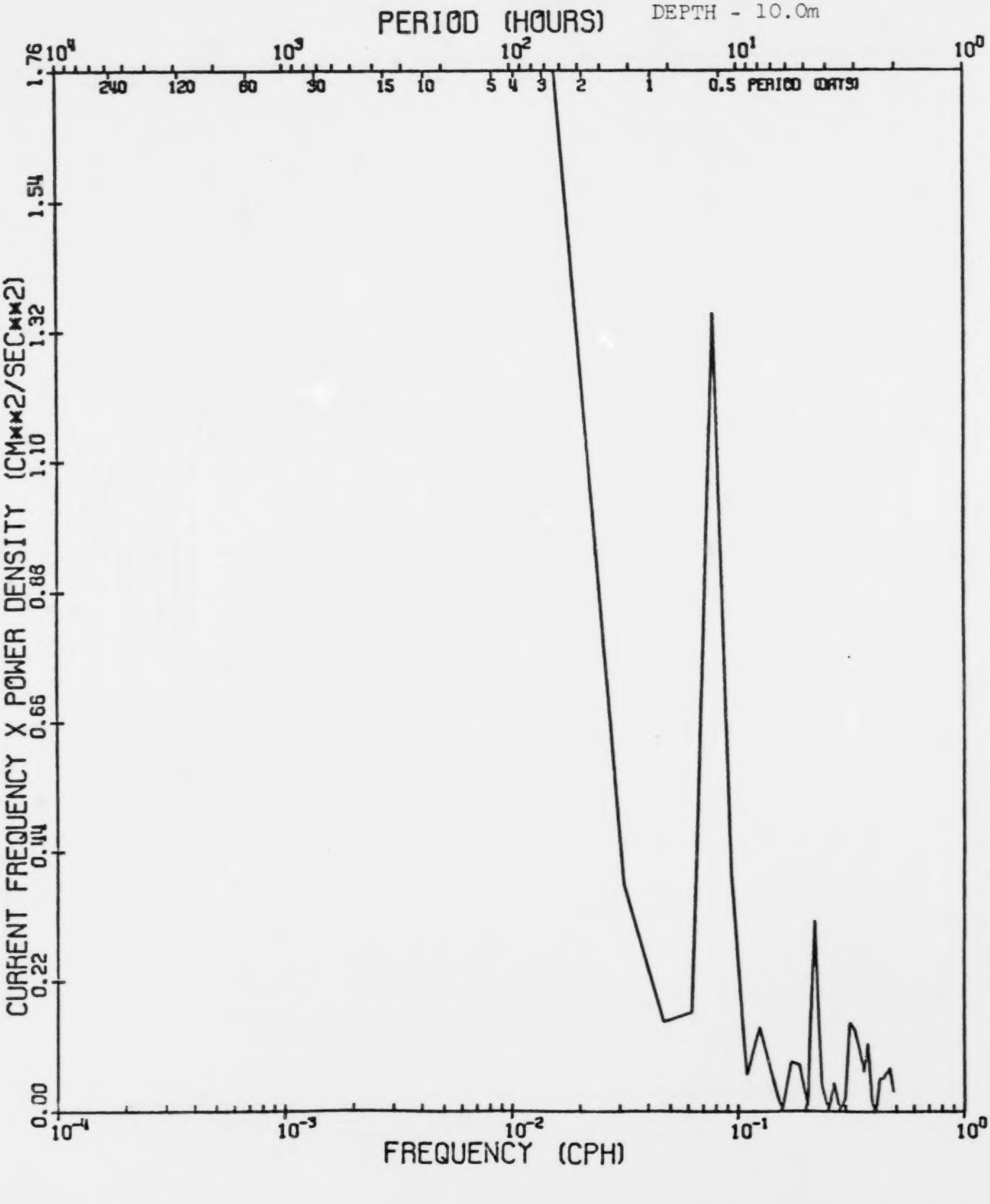


FIGURE 109

START TIME = 76051011

STOP TIME = 76053118

DEPTH -10.0m

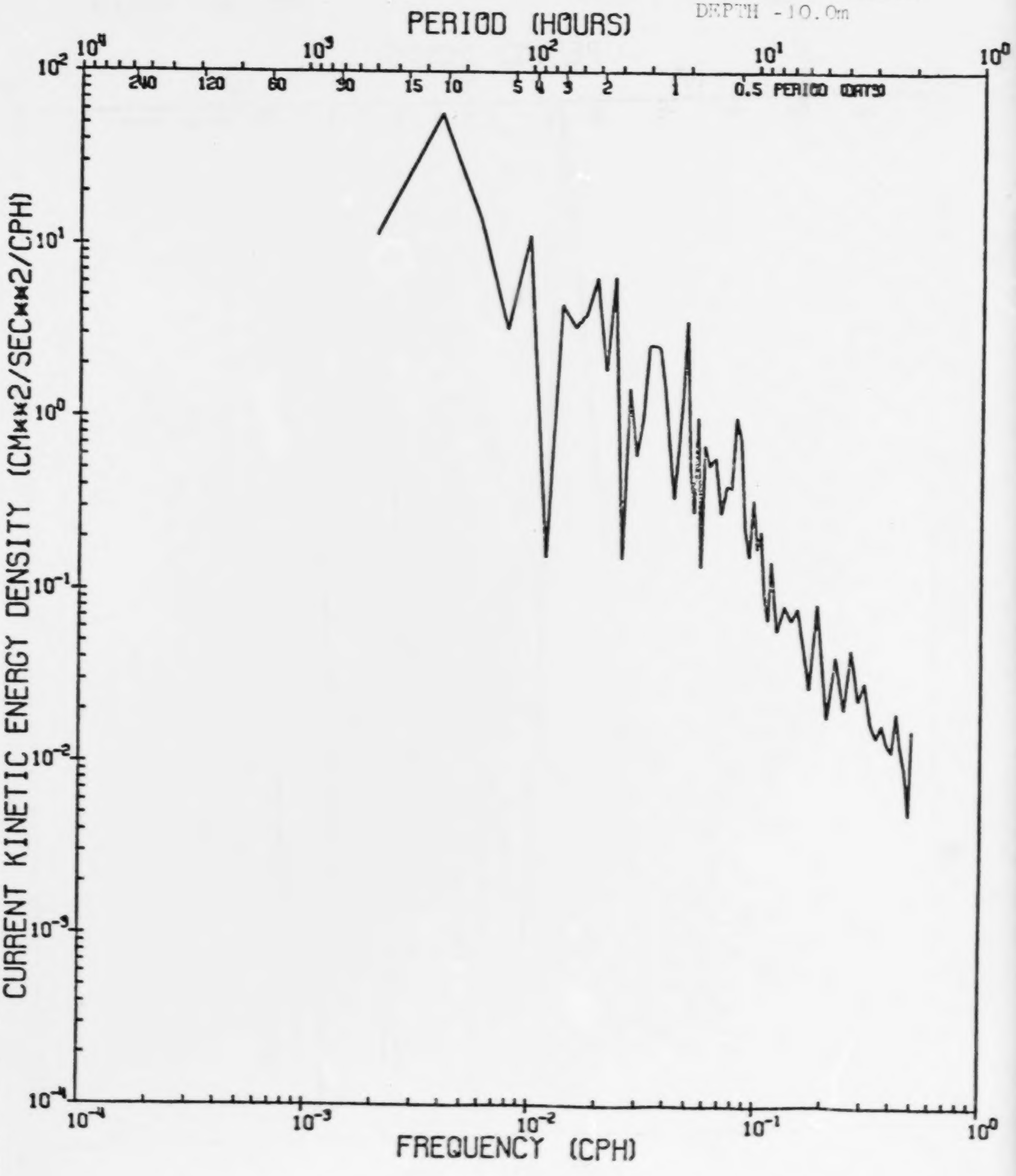


FIGURE 110

START TIME = 76051011

STOP TIME = 76053118

DEPTH - 10.0m

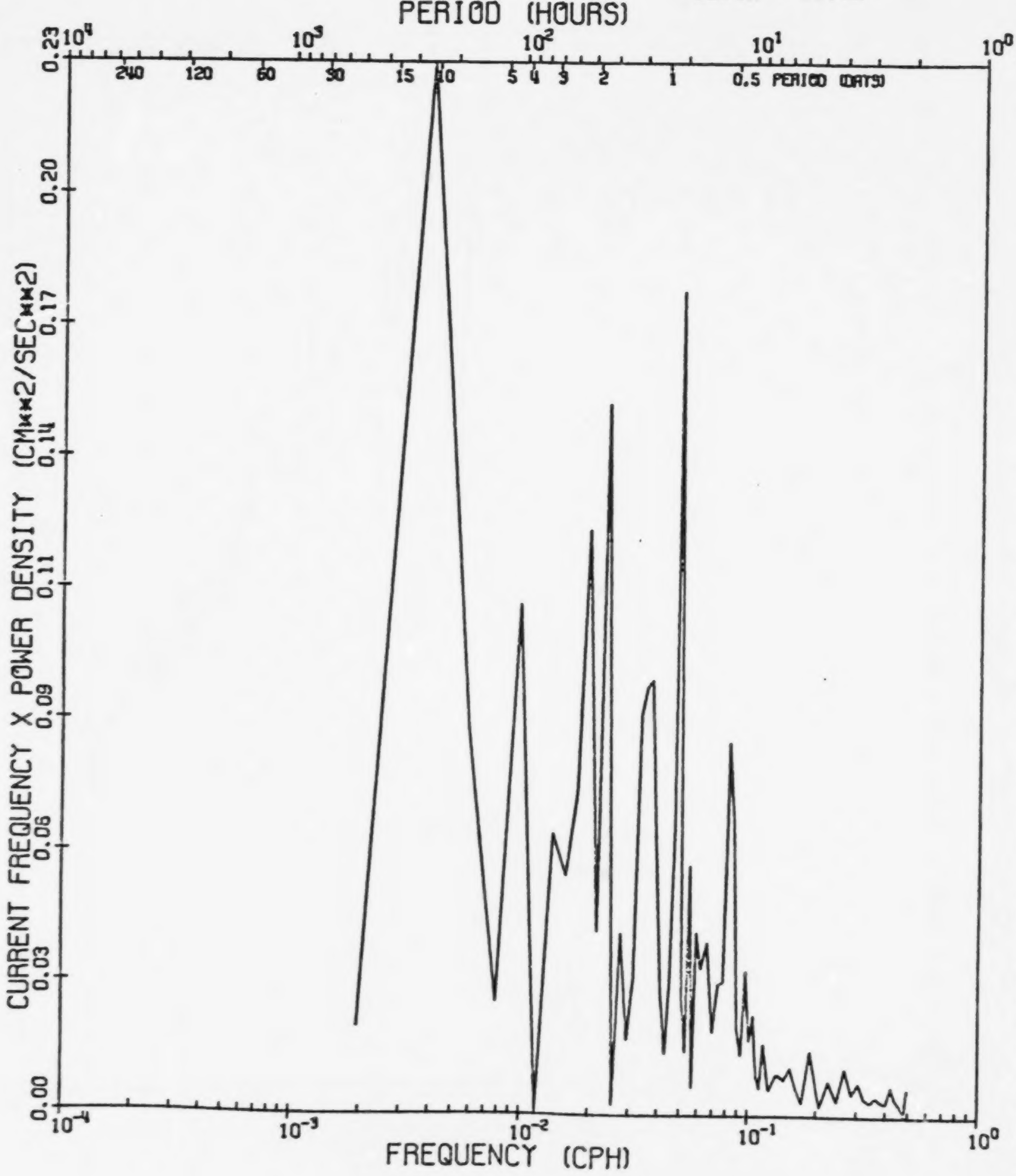


FIGURE 111

START TIME = 76061011

STOP TIME = 76072302

DEPTH -10.0m

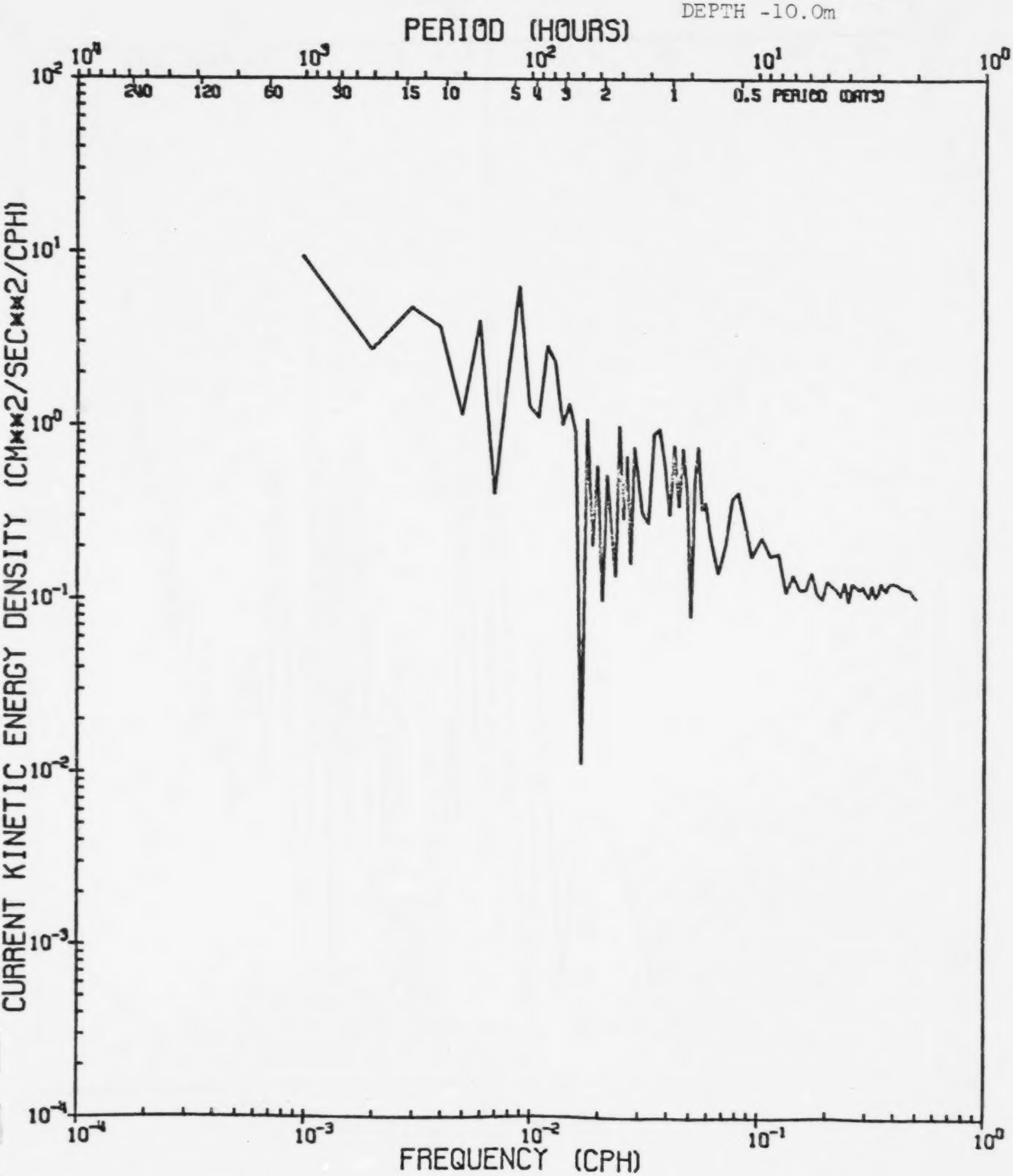


FIGURE 112
START TIME = 76061011
STOP TIME = 76072302
DEPTH - 10.0m

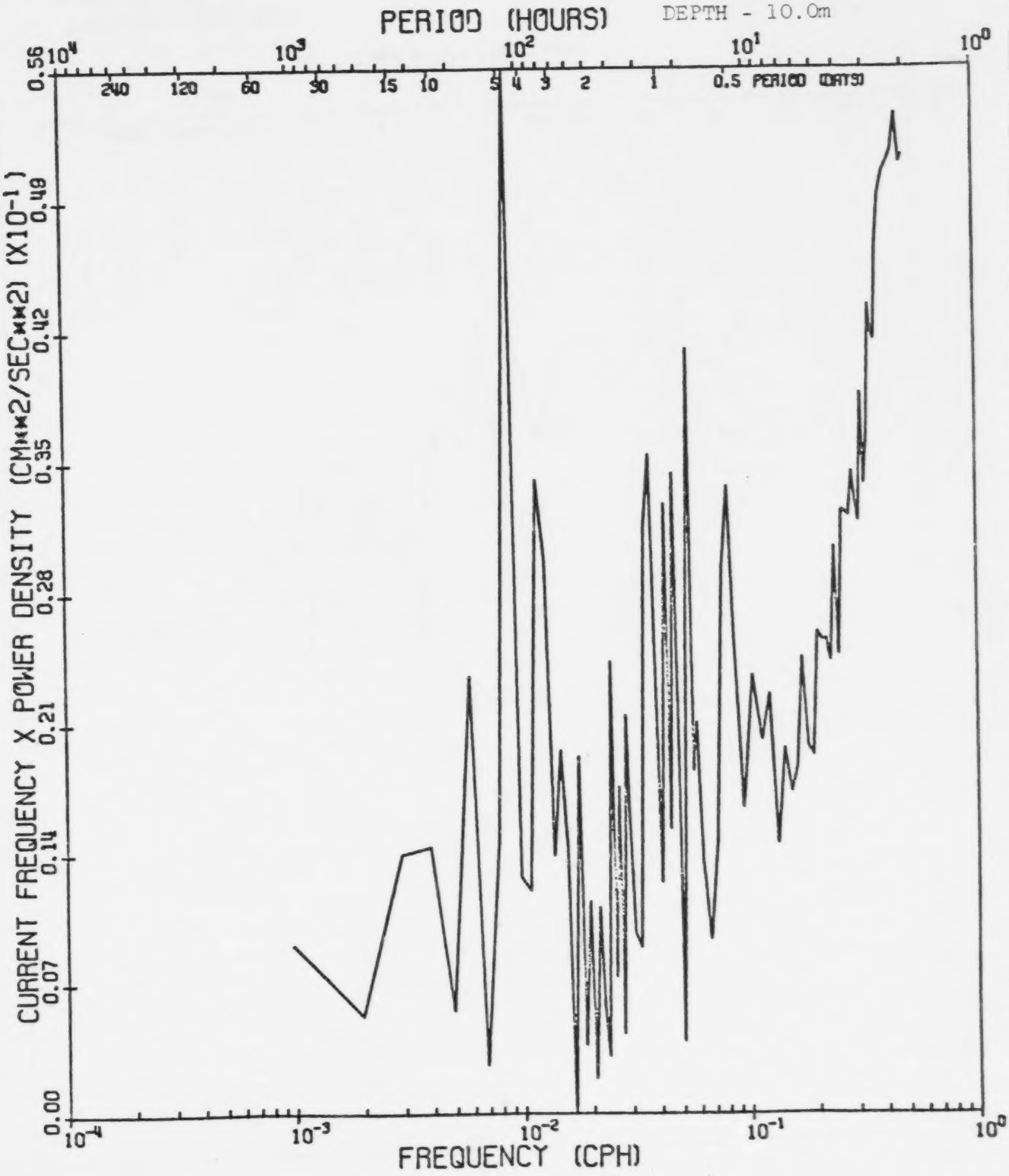


FIGURE 113

START TIME = 76090812

STOP TIME = 76092919

DEPTH -10.0m

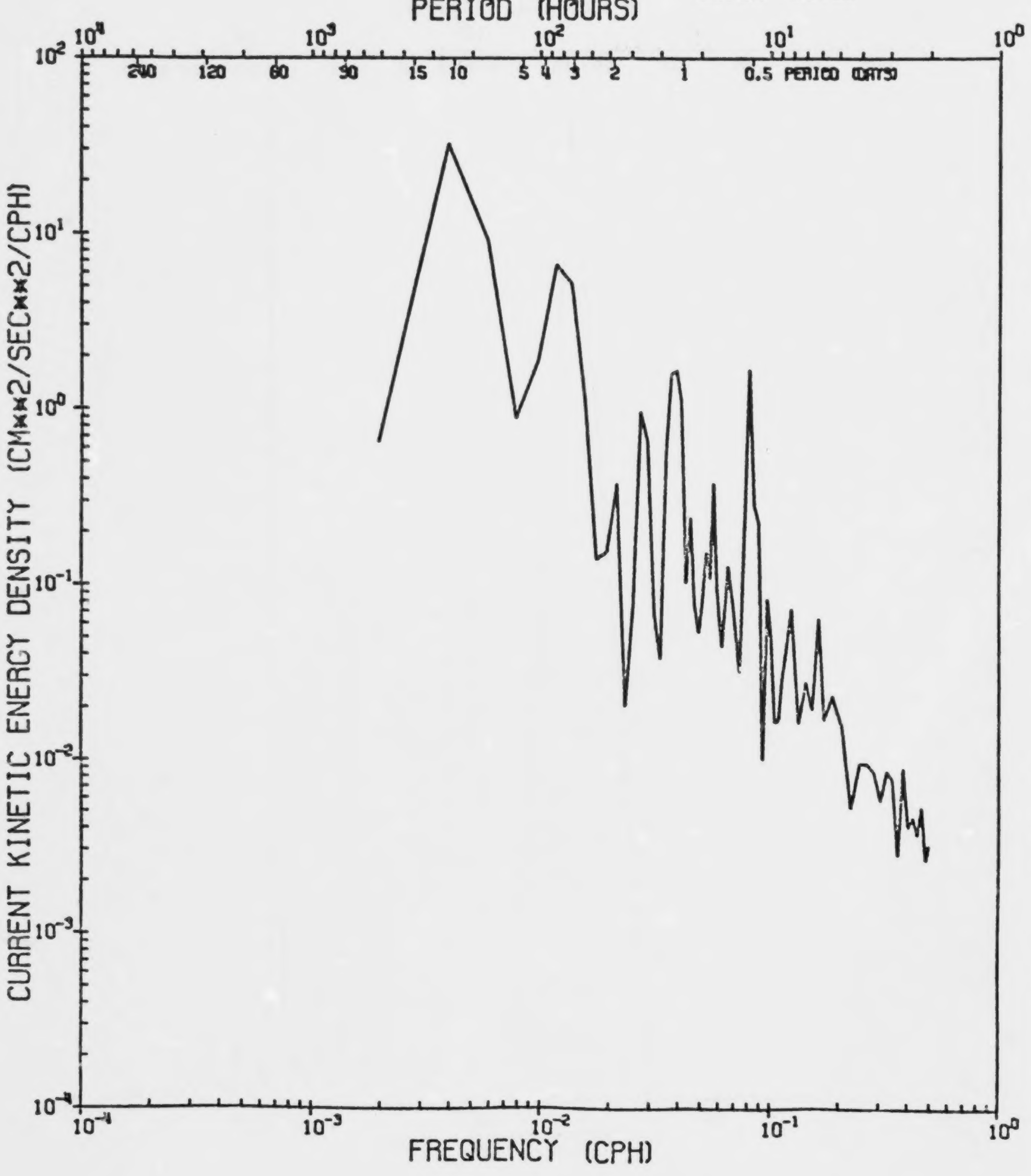


FIGURE 114

START TIME = 76090812

STOP TIME = 76092919

DEPTH - 10.0m

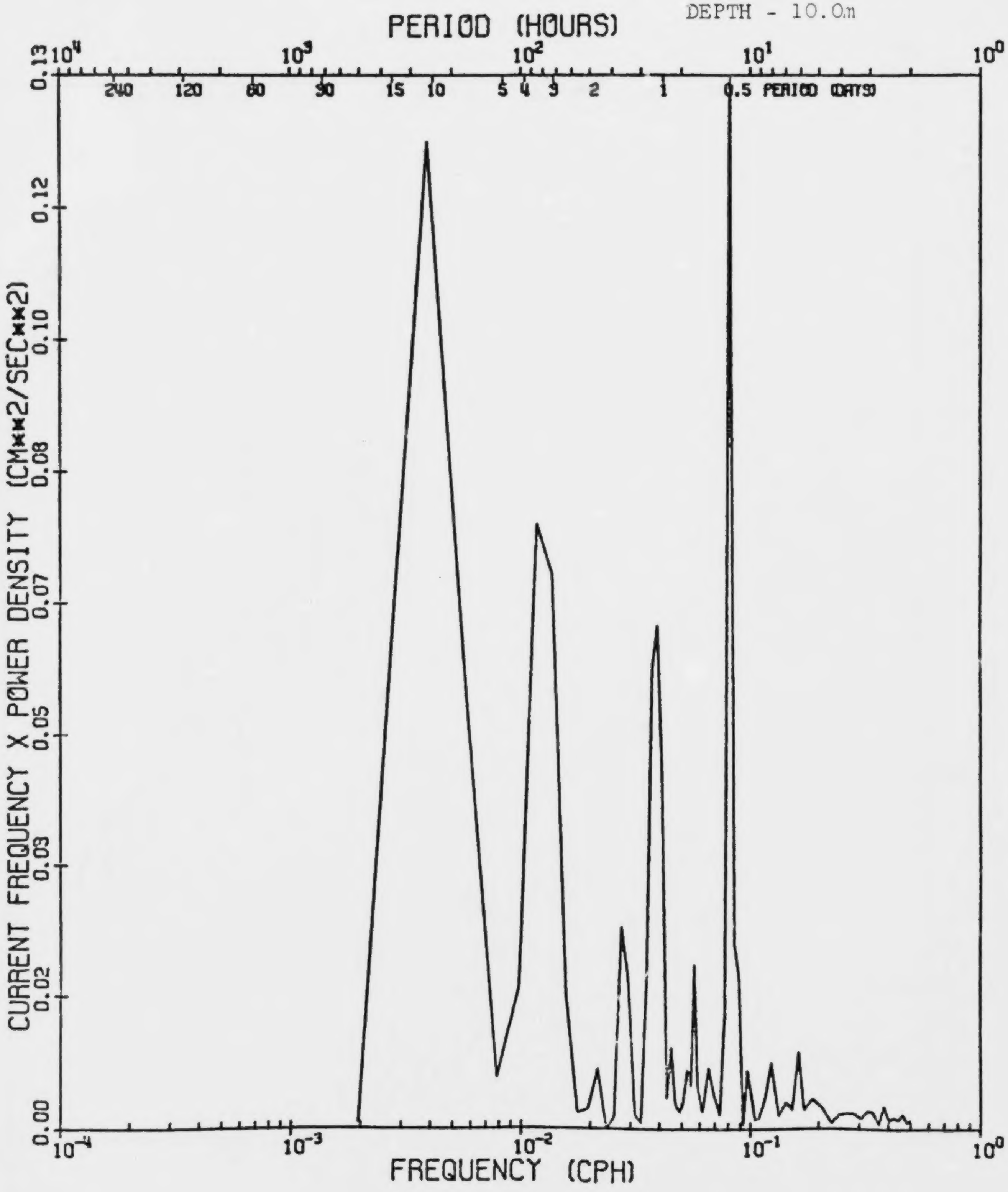


FIGURE 115

START TIME = 76032314

STOP TIME = 76032605

DEPTH -17.7m

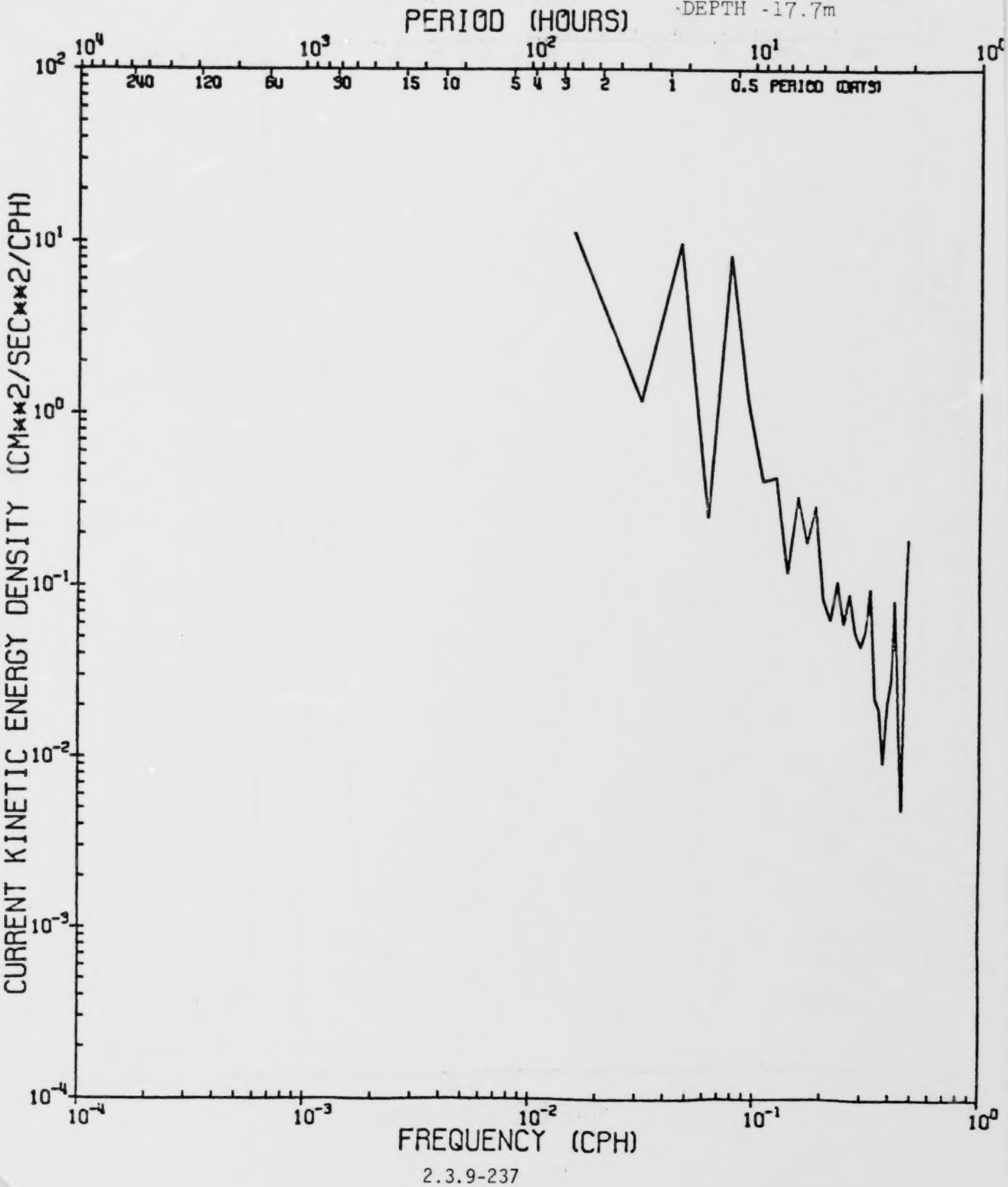


FIGURE 116

START TIME = 76032314

STOP TIME = 76032605

DEPTH - 17.7m

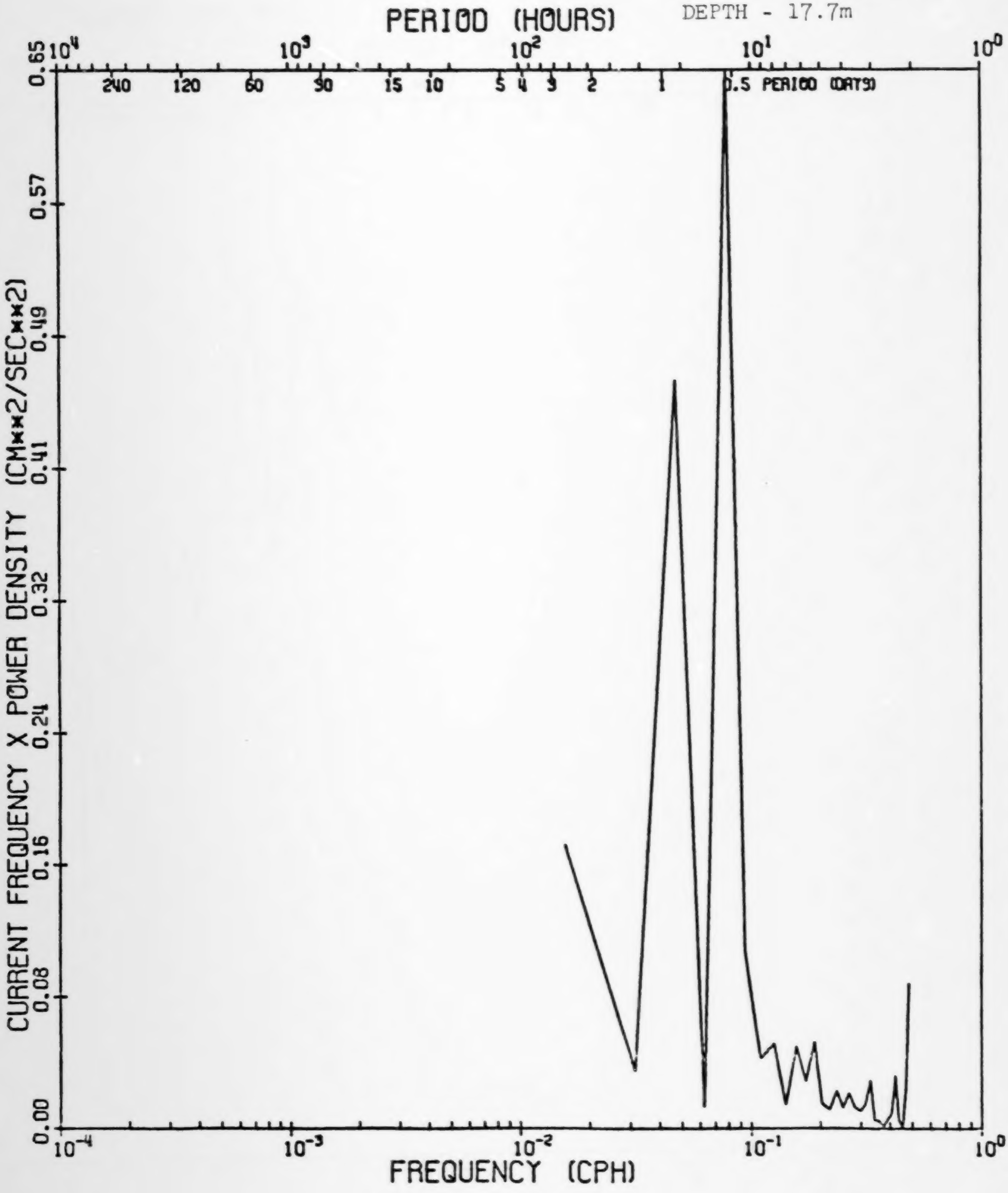


FIGURE 117

START TIME = 76040810

STOP TIME = 76041317

DEPTH -17.7m

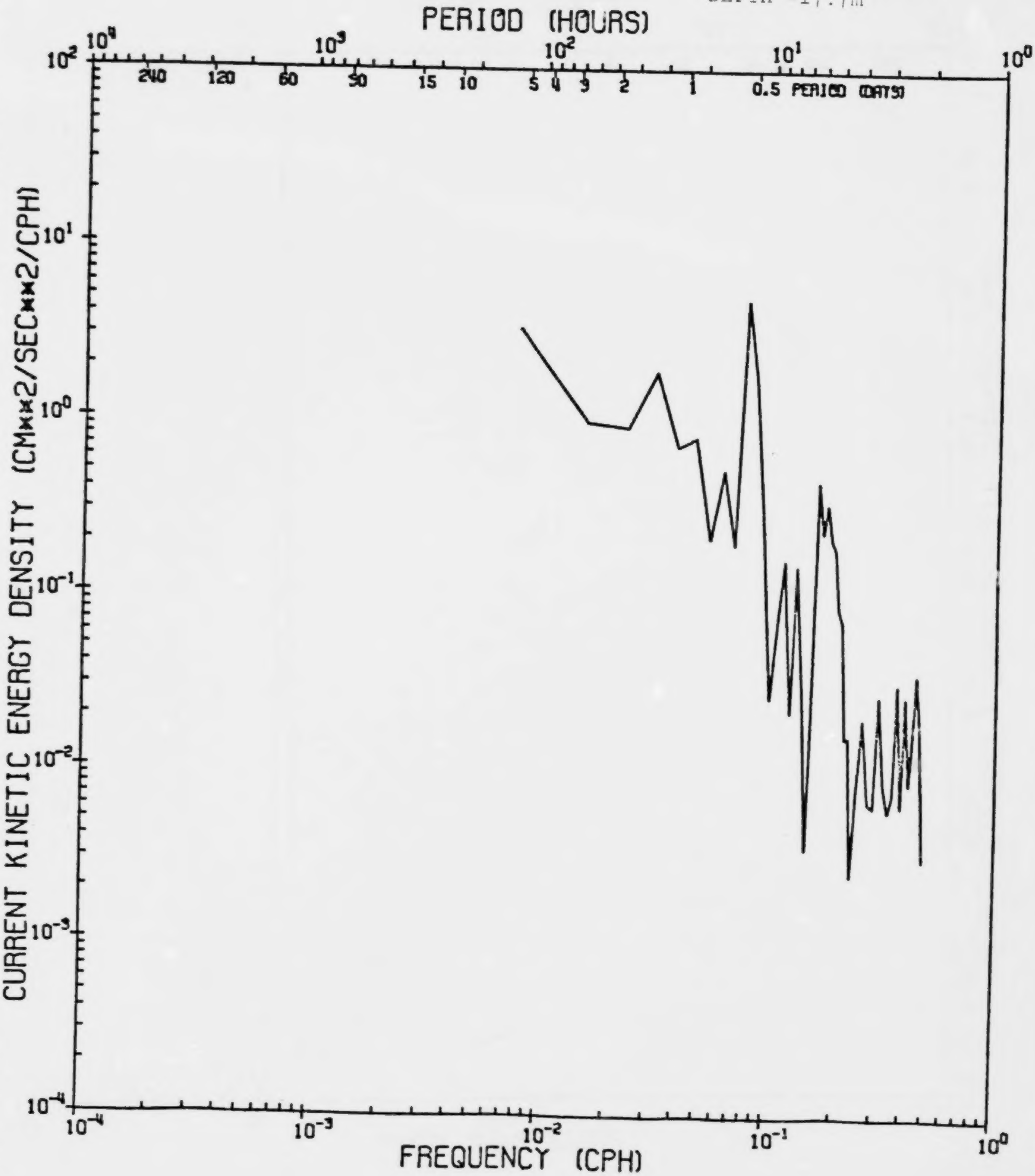


FIGURE 118

START TIME = 76040810

STOP TIME = 76041317

DEPTH - 17.7m

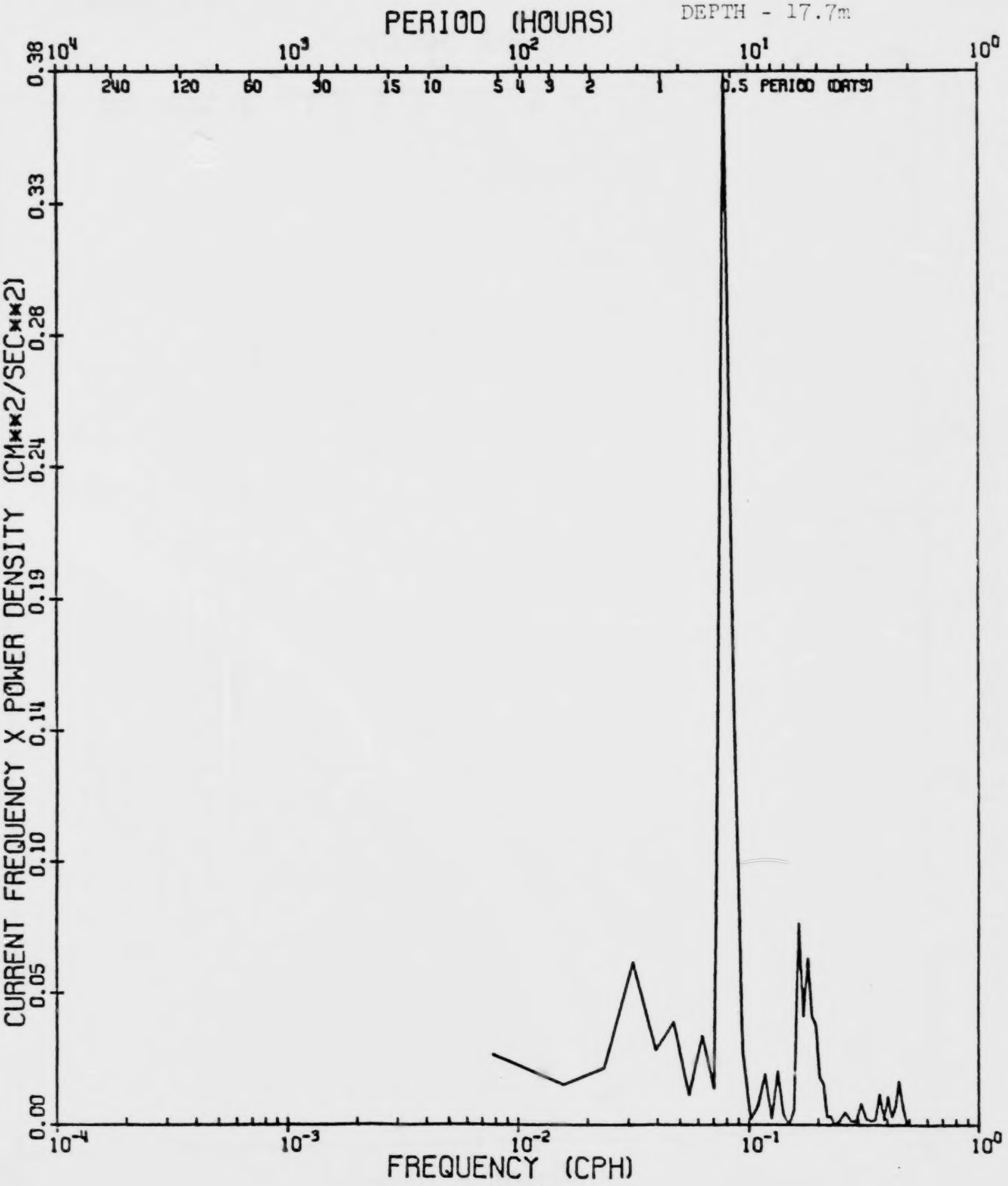


FIGURE 119

START TIME = 76051011

STOP TIME = 76051302

DEPTH -17.7m

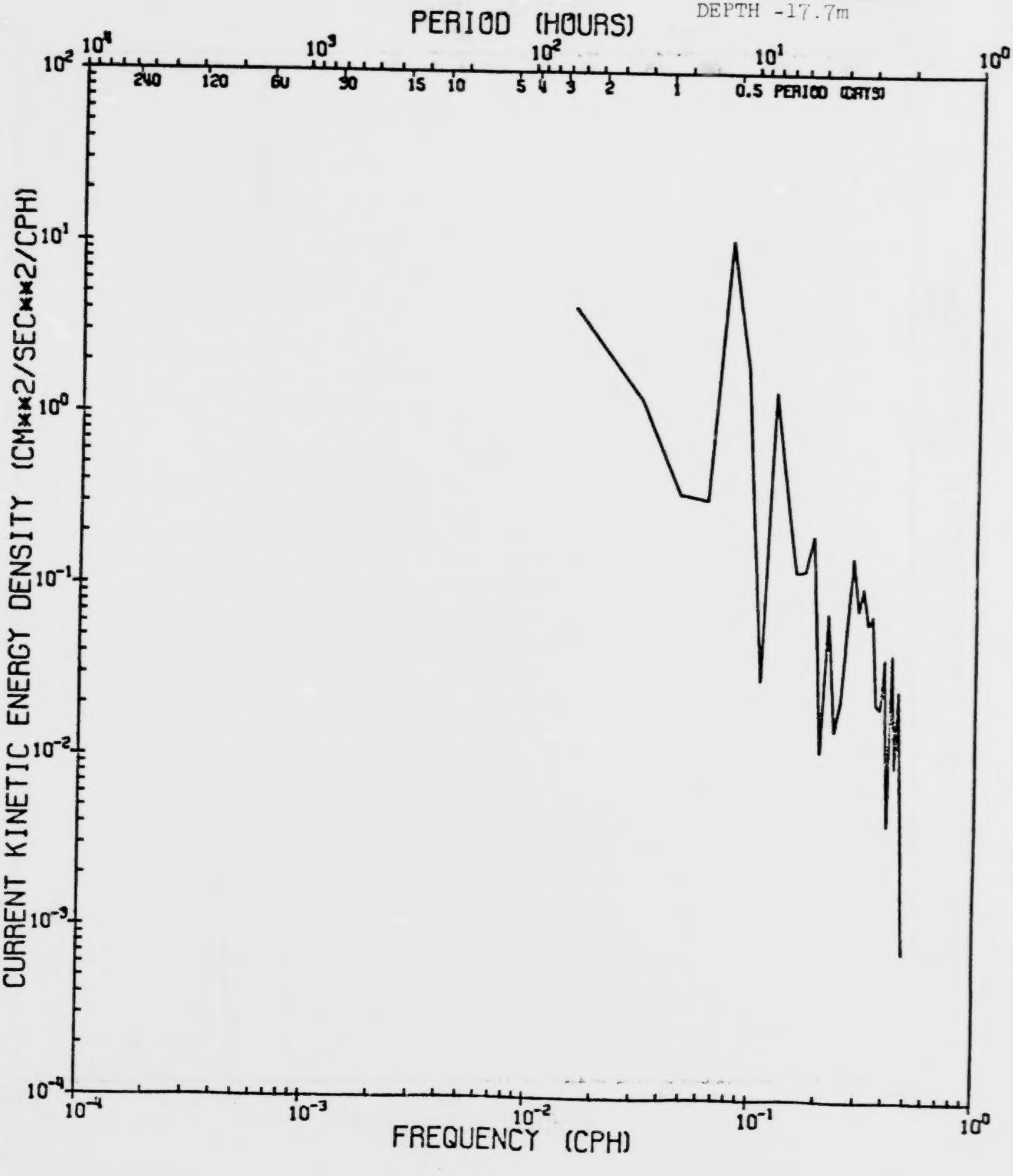


FIGURE 120

START TIME = 76051011

STOP TIME = 76051302

DEPTH - 17.7m

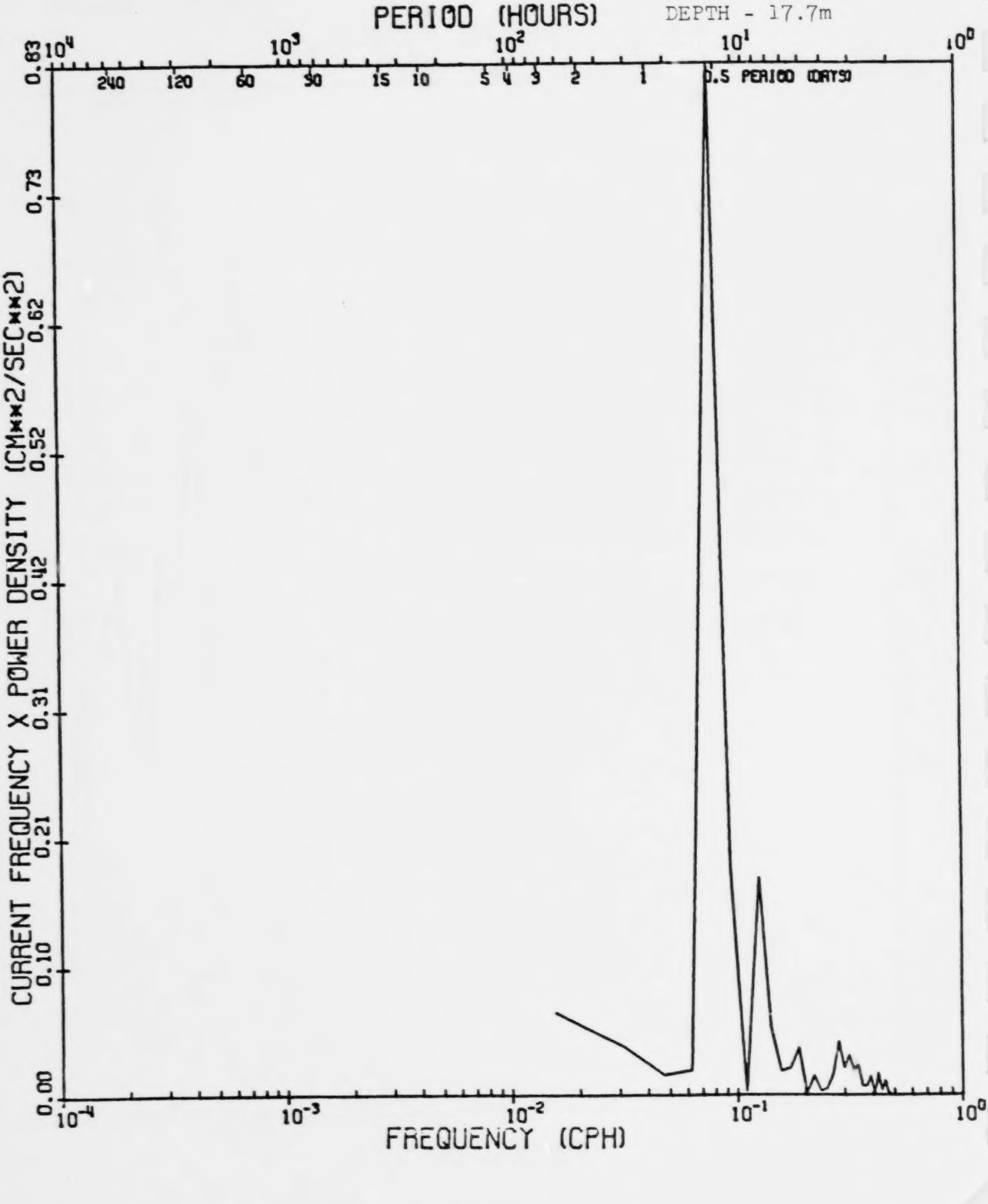
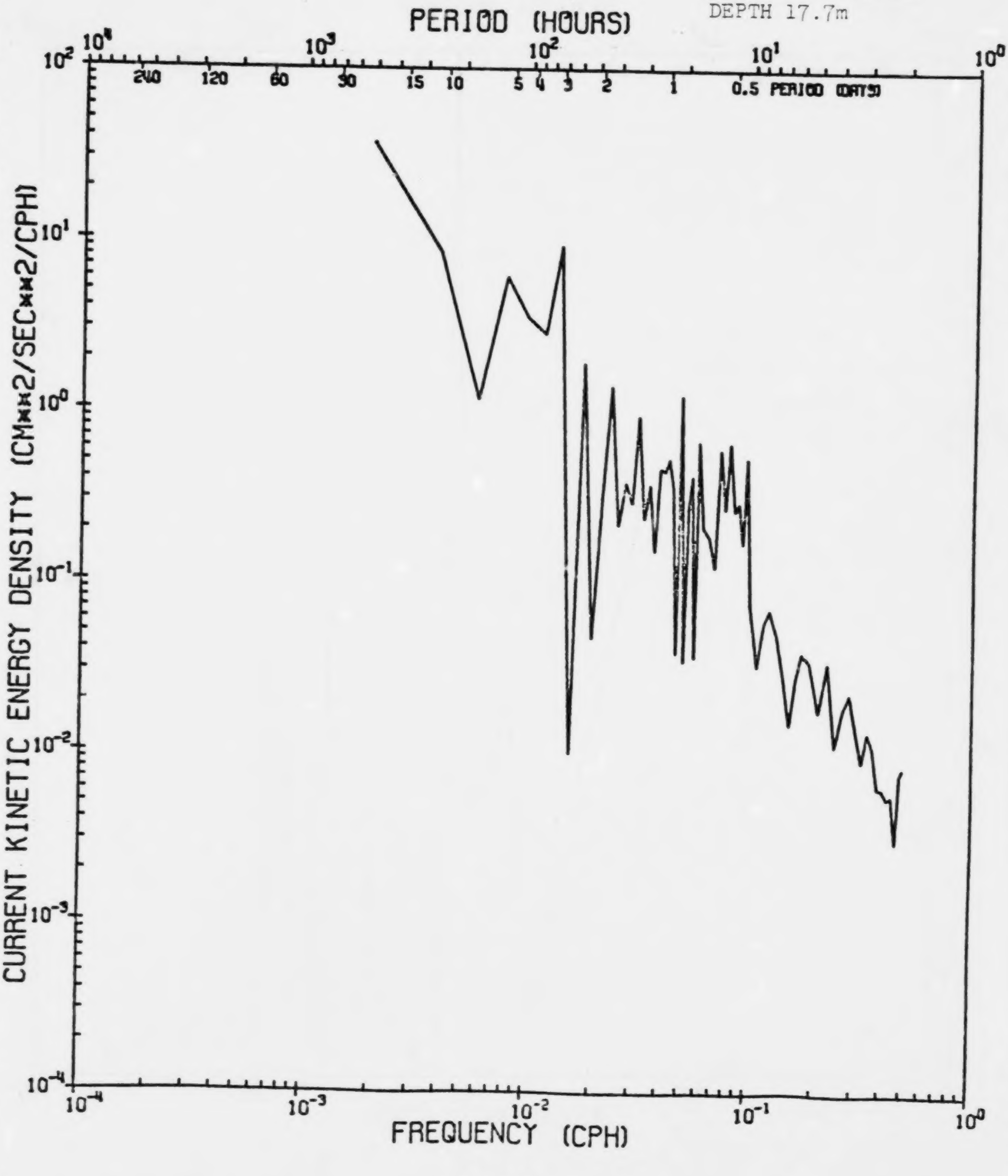


FIGURE 121

START TIME = 76051816

STOP TIME = 76060823

DEPTH 17.7m



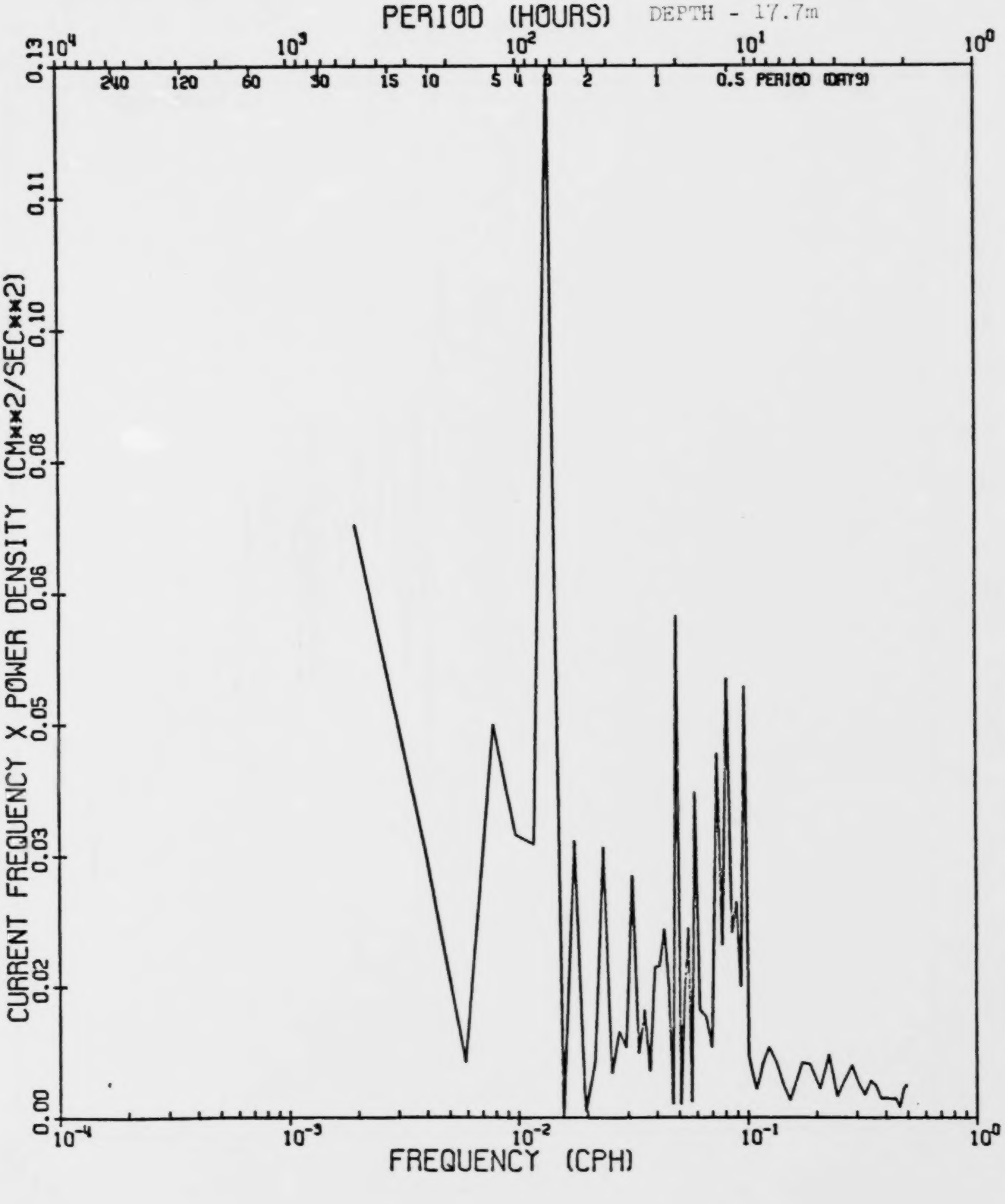


FIGURE 122

START TIME = 76051816

STOP TIME = 76060823

DEPTH - 17.7m

FIGURE 123
START TIME = 76061011
STOP TIME = 76072302
DEPTH -17.7m

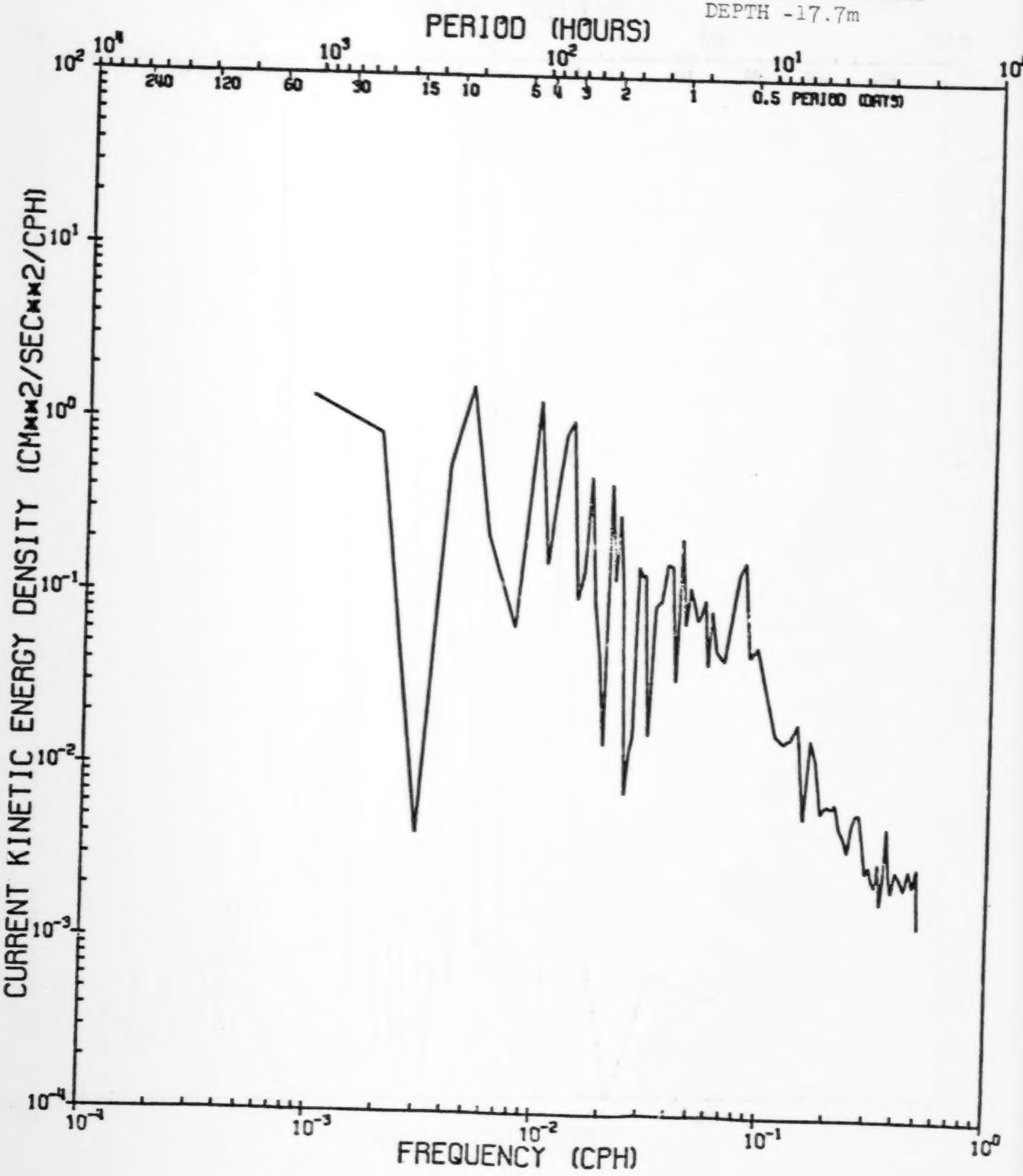


FIGURE 124

START TIME = 76061011

STOP TIME = 76072302

DEPTH - 17.7m

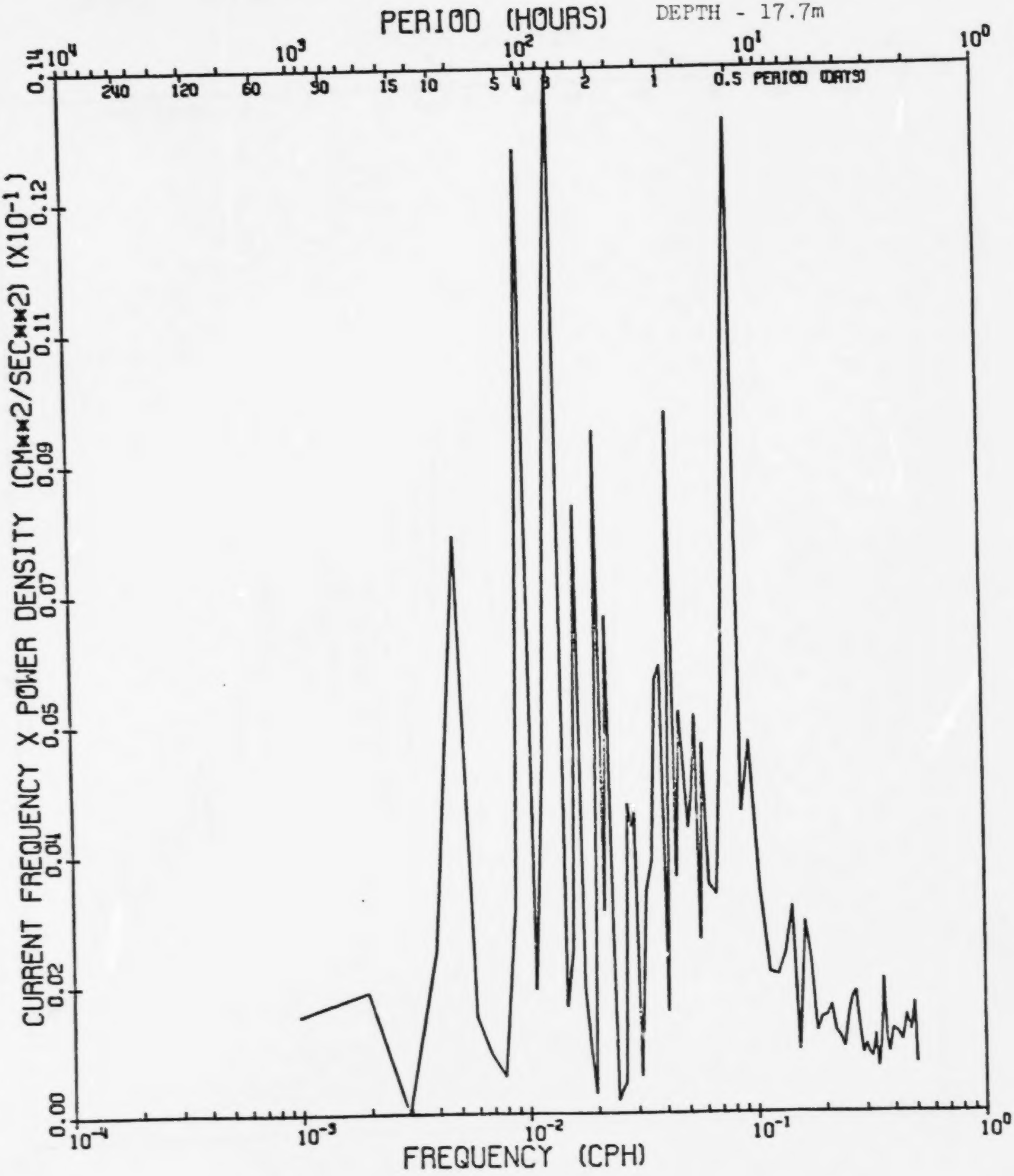


FIGURE 125

START TIME = 76081313

STOP TIME = 76092504

DEPTH -17.7m

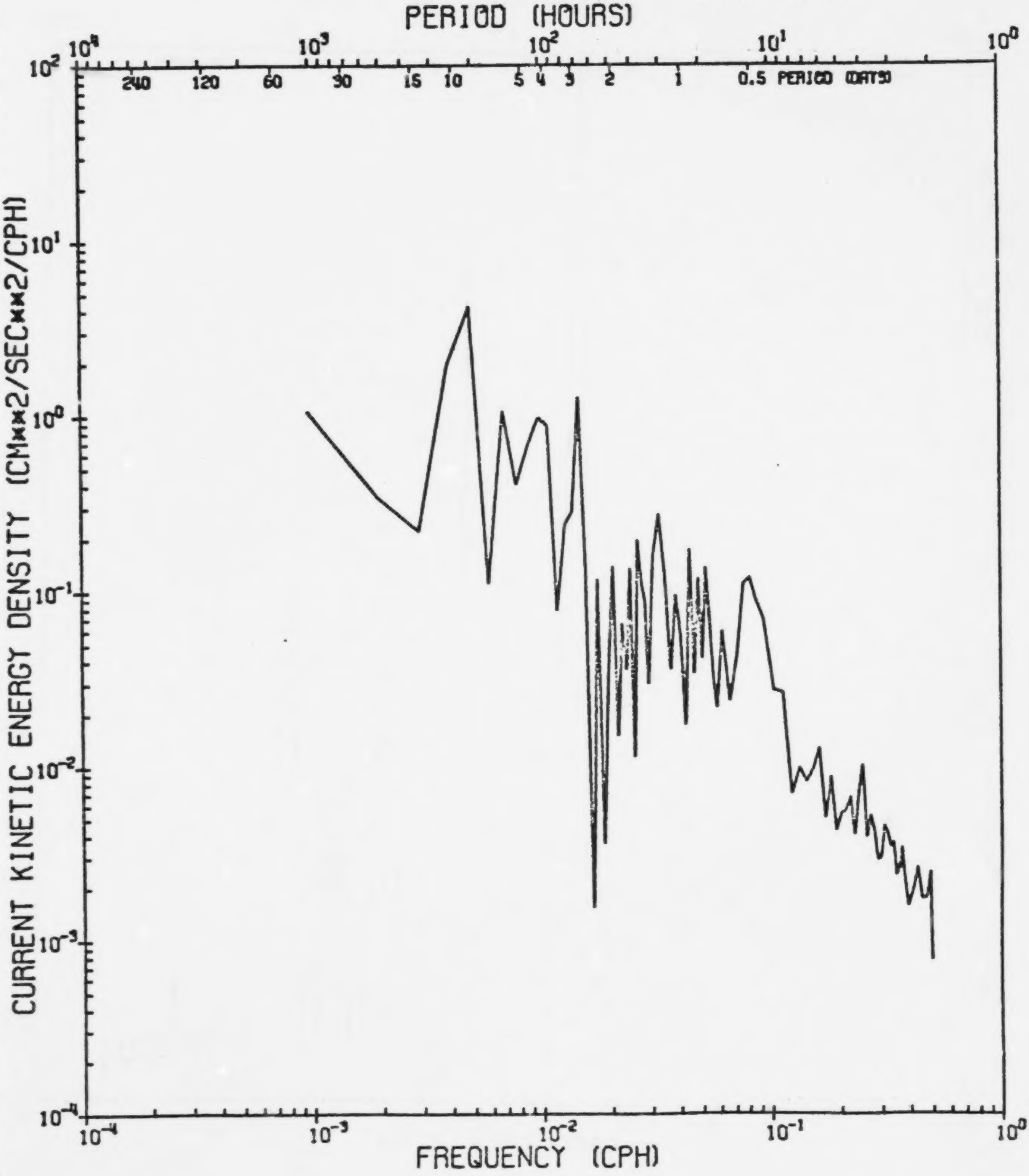
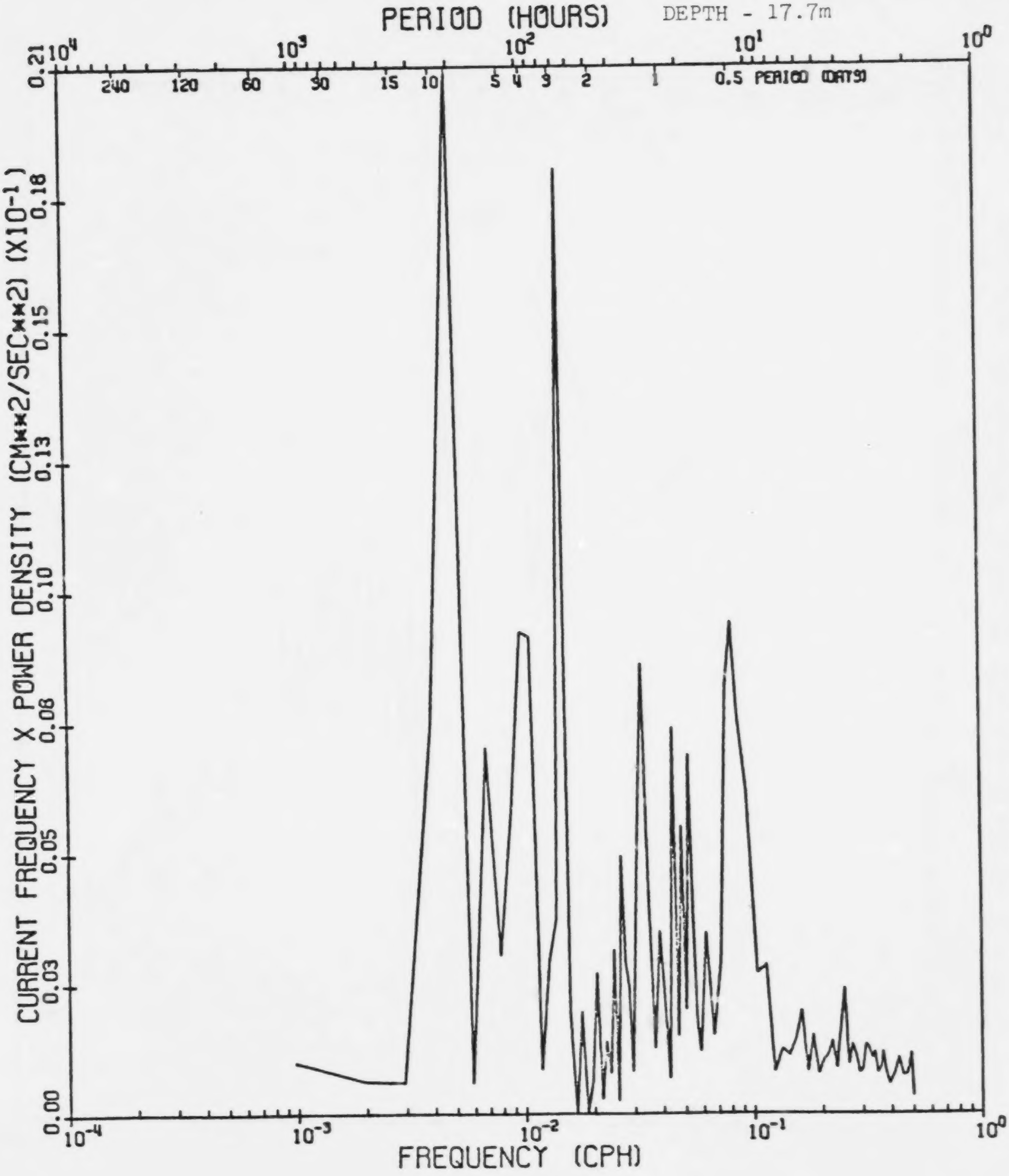


FIGURE 126

START TIME = 76081313

STOP TIME = 76092504

DEPTH - 17.7m



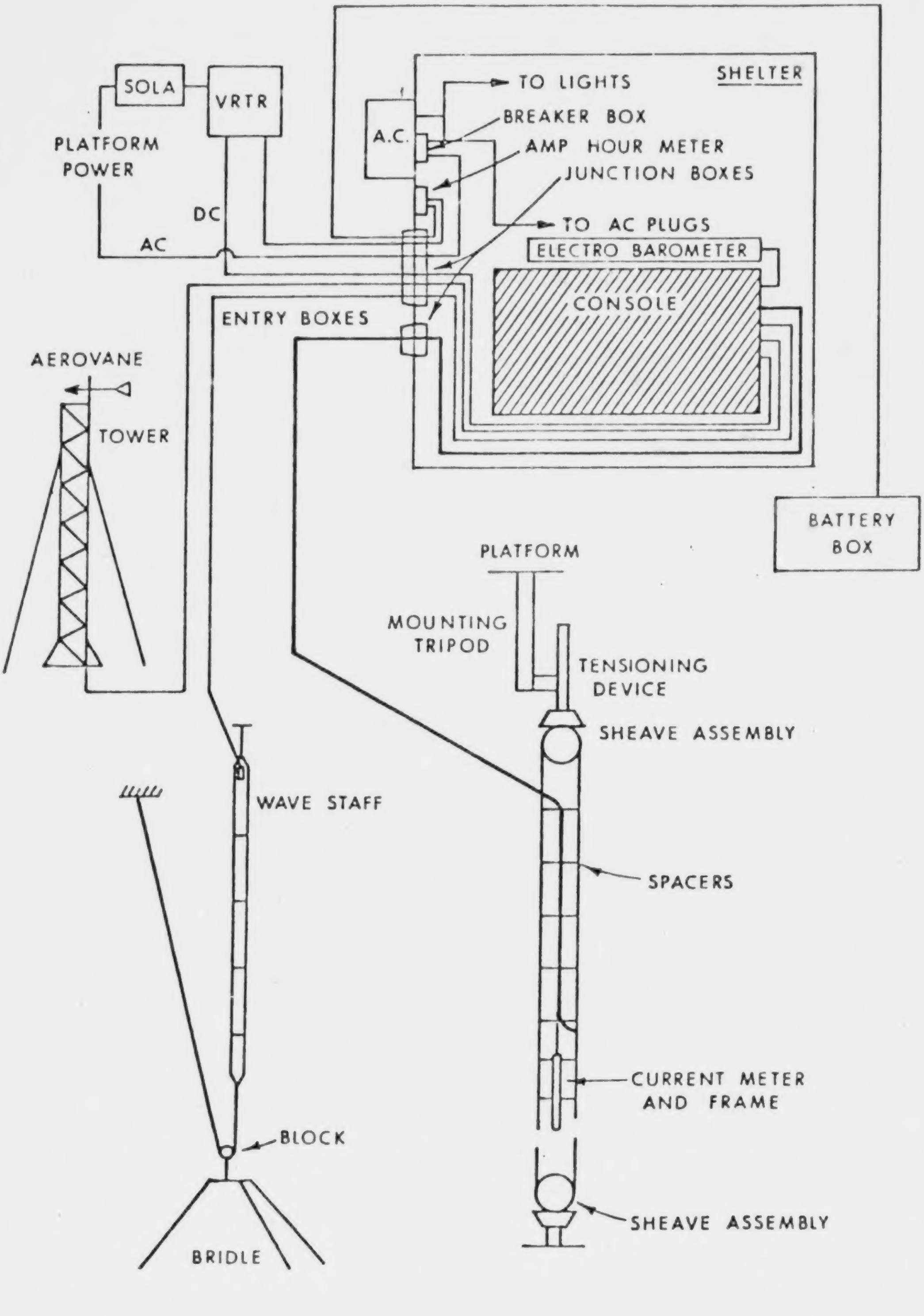

SOLA
VRTR
PLATFORM POWER
DC
AC
A.C.
TO LIGHTS
SHELTER
BREAKER BOX
AMP HOUR METER
JUNCTION BOXES
TO AC PLUGS
ELECTRO BAROMETER
CONSOLE
ENTRY BOXES
AEROVANE
TOWER
BATTERY BOX
PLATFORM
MOUNTING TRIPOD
TENSIONING DEVICE
SHEAVE ASSEMBLY
WAVE STAFF
SPACERS
CURRENT METER AND FRAME
BLOCK
SHEAVE ASSEMBLY
BRIDLE

Fig.127 - OCMP - System layout.

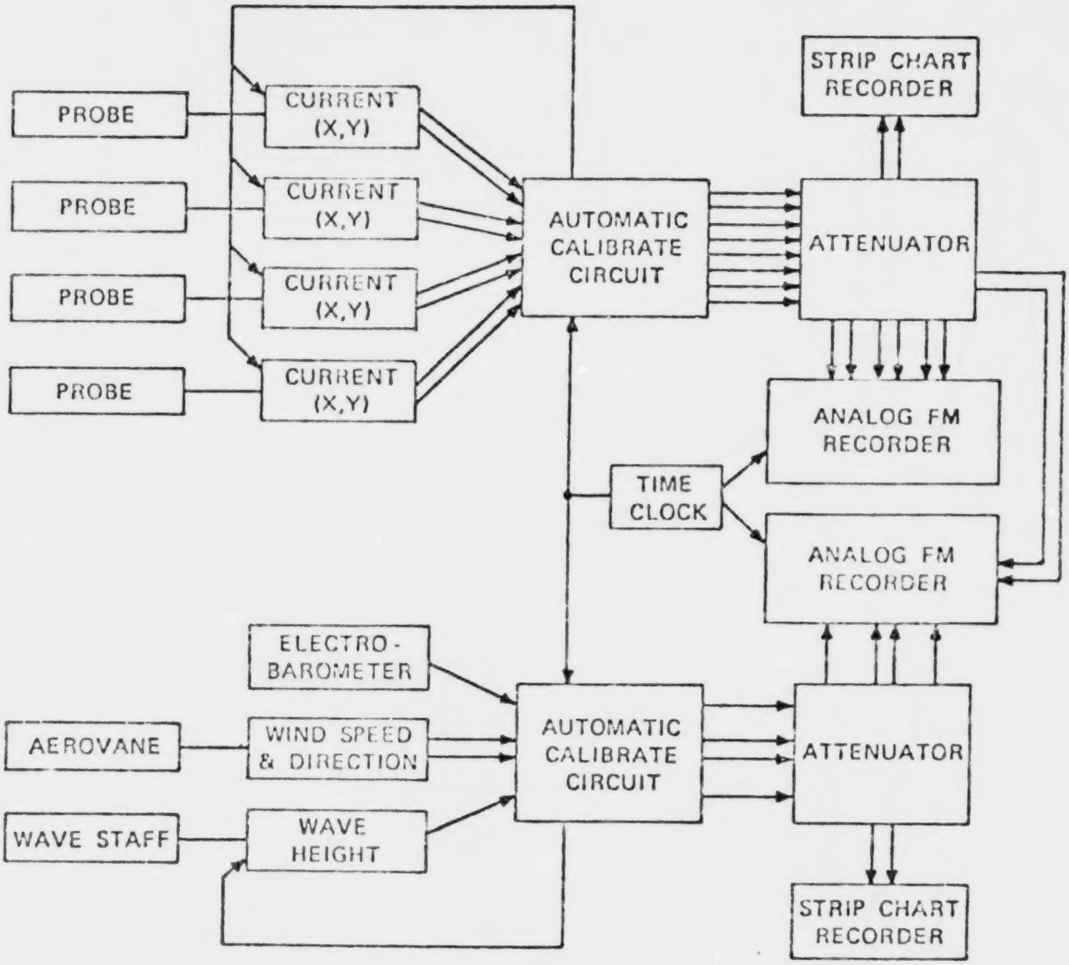

PROBE
PROBE
PROBE
PROBE
CURRENT (X,Y)
CURRENT (X,Y)
CURRENT (X,Y)
CURRENT (X,Y)
AUTOMATIC CALIBRATE CIRCUIT
STRIP CHART RECORDER
ATTENUATOR
ANALOG FM RECORDER
TIME CLOCK
ANALOG FM RECORDER
ELECTRO-BAROMETER
AEROVANE
WIND SPEED & DIRECTION
WAVE STAFF
WAVE HEIGHT
AUTOMATIC CALIBRATE CIRCUIT
ATTENUATOR
STRIP CHART RECORDER

Fig.128 - OCMP - Signal diagram.

Work Unit 2.4.1 Determine Levels, Pathways, and Bioaccumulation of Selected Discharge Constituents (Non-Metals) in the Marine Ecosystem in the Oil Field/Hydrocarbon Modeling

PART A

University of Houston

B. S. Middleditch

B. Basile

Part B

University of Houston

B. S. Middleditch

B. Basile

S. R. Missler

Part A

EXECUTIVE SUMMARY

This integrated report contains data from the first two years of our participation in the study. The major environmental contaminant discharged from the production platforms is elemental sulfur. Being heavier than water, the sulfur settles to the sediment and apparently supports a population of sulfur-utilizing bacteria which, in turn, produce high molecular weight alkanes. These biogenic alkanes have been found in bottom water samples in concentrations comparable to those of petroleum alkanes in surface water samples. These alkanes are assumed to be non-toxic and apparently pose no threat to the environment. Rather, it is tempting to speculate that the sulfur-utilizing bacteria comprise the base of the food web in the region of the oilfield. Most of the oil discharged from the production platforms floats at the air/sea interface, but a significant quantity is actively transported to the sediment. The mechanism of this transfer is not known with certainty, but it is suspected that fecal pellets of zooplankton and/or other fauna are involved in this process. Alkane concentrations in surficial sediment samples collected from below the production platforms are higher than in discharged brine. A concentration gradient exists in the immediate vicinity of these platforms, with alkane concentrations decreasing with increasing distance from the platforms. Petroleum hydrocarbons are present in some biota from the study area, but insufficient numbers have been analyzed to determine the significance of this finding. Preliminary analytical data are given for the sewage discharge from one of the quarters platforms.

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EXECUTIVE SUMMARY

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INTRODUCTION

BACKGROUND

Debate over the environmental effects of offshore oil production has been continuing ever since the concept of drilling at sea was introduced. On the one hand, there are those who wish to protect the environment from unreasonable assault and, on the other hand, there are pressures to produce more oil and to produce it as inexpensively as possible. In the United States, the latter concern has been compounded by a realization of the problems which can result from overdependence upon imported oil.

For a reasonable debate to proceed to a resulution of differences of opinion, reliable and appropriate data must be made available. Many studies have been made of the environmental effects of major oil spills and well blowouts. Much data has been obtained concerning the toxicity of oil and its components on marine organisms. However, at the inception of this project, little was known about the environmental effects of routine offshore oil production.

We chose, therefore, to obtain data which were both reliable and relevant to the problem. Initially, we focused our studies on the the nature and amounts of the hydrocarbons discharged from the production platforms and on their subsequent distribution and disposition. During the course of this work we recognized the significance also of biocides and elemental sulfur in the discharges and have extended the study to include these substances.

This integrated report describes our contributions during the first two years of the ongoing study.

Catastrophic Events

One of the first tanker accidents to receive international attention occurred in 1967 when the "Torrey Canyon" grounded off the southwest coast of England. Approximately 29.4 million gallons of Kuwait crude oil were released, much of which reached the beaches of England and France. However, in this case, the deleterious effects of the spill have been attributed more to the detergents used to disperse the oil than to the oil itself (Nelson-Smith, 1973).

When the oil barge "Florida" ran aground just off Little Island, West Falmouth, Massachusetts in 1969, approximately 175,000 gallons of Number Two fuel oil leaked into Buzzards Bay and the adjacent Wild Harbor Marsh. Scientists from the nearby Woods Hole Oceanographic Institution were able to study the incorporation of polluting hydrocarbons into the marsh ecosystem. Massive kills of marine and marsh life were reported immediately after the spill and oysters and scallops were found to be contaminated with fuel oil (Blumer *et al.*, 1970). Analyses of sediments and marsh organisms collected a year later showed an accumulation of petroleum hydrocarbons. Chromatograms of pentane extracts revealed the loss of lower boiling components of the oil, and the accumulation of cyclic and aromatic hydrocarbons (Burns and Teal, 1971; Blumer *et al.*, 1973). Sediments examined two years after the spill still demonstrated the persistence of fuel oil hydrocarbons (Blumer and Sass, 1972).

When the tanker "Argo Merchant" went aground near Nantucket Island, Massachusetts on December 15, 1976 more than 7.7 million gallons of number six fuel oil were lost. Immediately after the wreck scientists from throughout the U.S. began to make an assessment of the impact of spilled oil on the ecology of the area. Analysis of sediments collected within two months of the spill did not indicate the presence of oil in significant quantities, except within 10 miles of the bow section, where concentrations up to 100 ppm were measured in a few samples. There was evidence of oil contamination in fish, shellfish, ichthyoplankton, and other zooplankton in the area of the spill. Benthic filter-feeders such as mussels, scallops and quahogs, however, did not then show an accumulation of hydrocarbons (Grose and Mattson, 1977).

Unlike the conclusions from tanker spill studies, examination of the effects of an oil well blowout did not reveal substantial ecological damage. Up to 3.25 million gallons were lost when the Union Oil well A-21 off Santa Barbara, California began to leak after a successfully contained blow-out in January, 1969. Studies of phytoplankton productivity showed normal conditions from the nutrient levels recorded, and the mortality of 13% among full-term pups in island colonies of sea lions and elephant seals were within the normal range of 12-15%, even though the islands were surrounded by heavy oil slicks (Nelson-Smith, 1973). However it has been argued that if sophisticated chemical analysis techniques applied to the West Falmouth spill had been applied systematically to the Santa Barbara spill, a more serious picture of ecological damage would be available (Easton, 1972).

While scientists and environmentalists debate the effects of oil pollution, tanker disasters are occurring. In the largest spill recorded, the tanker "Amoco Cadiz" released 65 million gallons of crude oil after grounding off the coast of Brittany on March 16, 1978 (Anon., 1978). Yet, despite the attendant publicity and financial losses, the comprehensive evaluations of oil spill pollution often last less than two years. These events need comprehensive, long-term studies by multidisciplinary teams of scientists in order to effectively evaluate environmental problems that oil spill pollution causes.

Biological Effects

The effects of oil on marine organisms can be categorized as:

1. direct lethal toxicity;
2. sub-lethal disruption of physiological or behavioral activities;
3. effects of direct coating by oil;
4. incorporation of hydrocarbons in organisms which may cause tainting or the accumulation of hydrocarbons in food chains; and
5. changes in biological habitats (Moore and Dwyer, 1974).

Most of the data on toxicity are reported in the form of LD_{50} values, the concentrations of oil which will produce 50% mortality in a population of test organisms over a given period of time. However, problems of comparing and interpreting different laboratory studies arise due to dissimilarity in experimental conditions and the lack of measurement of hydrocarbon concentrations. Some investigators estimate "soluble aromatic derivative" (SAD) in order to compare data. On this basis Moore and Dwyer (1974) postulated a direct lethal response in most adult marine species after exposure to 1-100 ppm total SAD for periods of several hours and in larval stages after exposure to 0.1-0.9 ppm total SAD. Sub-lethal disruption of behavioral activities could occur at concentrations as low as 10-100 ppb.

The various fractions of crude oil can also affect organisms in different manners. The low boiling saturated hydrocarbons can produce anesthesia and narcosis at low concentrations, and cell damage and death when present in greater concentrations. The higher boiling saturated hydrocarbons occur naturally in marine organisms and are not generally toxic. If they are present in large enough concentrations, however, they may interfere with nutrition and chemical communication (National Academy of Sciences, 1975). Olefinic hydrocarbons are present in limited amounts in crude oil but in larger quantities in some oil products. These compounds also are produced by marine organisms. The low boiling aromatic hydrocarbons (benzene, toluene, xylene, methylnaphthalenes, *etc.*) are poisons, while the higher boiling compounds (benzo[a]pyrene, *etc.*) are suspected of being long-term poisons or carcinogens (Blumer, 1969).

Natural Seeps

A parallel to the study of low level, chronic pollution in an oil production area is the study of the effects of natural petroleum seepage. The presence of oil seeps in the Santa Barbara Channel (California) has been documented as early as 1543 (Easton, 1972). In order to assess the consequences of this geological phenomenon, a series of field surveys was conducted in 1972 through 1974. Coal Oil Point, an area of natural oil seepage in the Santa Barbara Channel, was compared with control sites that were not chronically exposed to natural oil seepage. The studies were designed to encompass most segments of the environment, most invertebrate groups and most habitat types. Species examined were sedentary (non-migratory) to ensure that specimens had actually been exposed to conditions in the area.

Some of the most significant results were:

1. Animals are inhabiting areas of Coal Oil Point which have extremely high levels (up to 9%) of petroleum hydrocarbons in the sediments.
2. The distribution of petroleum hydrocarbons is patchy throughout the environment in terms of time, locations, and tissue type.
3. Total hydrocarbon values alone cannot be used as indicators of petroleum contamination due to the variability in composition of both petroleum and biogenic hydrocarbons.
4. No malformations were observed in the thousands of organisms examined from Coal Oil Point.
5. Specimens of abalone (*Haliotis* sp.), sea urchin (*Stronglylocentrotus purpuratus*), and mussel (*Mytilus californianus*) from Coal Oil Point are more tolerant of exposure to Santa Barbara crude oil and seem to be hardier in terms of survival and adjustment to laboratory conditions than animals from control locations (Straughan, 1976).

Offshore Drilling

Due to the paucity of data on the environmental impacts of petroleum drilling, the Gulf Universities Research Consortium (GURC) conducted an offshore ecology investigation (OEI) between June, 1972 and January, 1974.

The study was conducted in Timbalier Bay, Louisiana and the adjoining near-shore shelf region. In addition, samples were obtained in the vicinity of platforms experiencing drilling or prolonged intensive production and in control locations removed from the influence of production activity. Sampling sites were chosen so as to minimize the impact of the Mississippi River and yet to provide an ecologically contiguous area, and the duration of the study was sufficiently long-term to detect persistent impacts as well as short-term variations.

Conclusions based on the data generated are:

1. Concentrations of hydrocarbons and trace metals are sufficiently low (less than 11 ppb in the water column) to present no known persistent biological hazards. In fact, hydrocarbon concentrations in the water column, sediments and living organisms were of the same order of magnitude as those reported in the literature for the Atlantic Ocean or the Gulf of Mexico.

2. The region of sampling sites is highly productive from a biological standpoint, more than other regions studied in the eastern and open Gulf of Mexico.

3. Natural phenomena such as seasonality, floods, upwellings, and turbid layers have a much greater impact upon the ecosystem than do petroleum drilling and production activities.

4. Timbalier Bay has not undergone significant ecological change as a result of petroleum drilling and production since just prior to 1952 when more limited baseline data were gathered (Morgan _et al_., 1974).

Other investigations have focused upon sediments in the vicinity of oil production operations since this environmental compartment was postulated to be repository for residues of discharged oil. One offshore area studied was Lake Maracaibo, in the state of Zulia, Venezuela. Oil production has been localized in the northwest quadrant of the lake for 40 years, therefore appropriate control stations were chosen in other areas of the lake. The saturate fraction of sediment samples ranged from 250 ppm to 3700 ppm of hydrocarbons, while the aromatic fraction ranged from 430 ppm to 6600 ppm. The quantity of organic material extracted decreased as the distance from the production zone increases (Bean _et al_., 1977).

In a statistical comparison of data generated by various government regulatory agencies, Travers and Luney (1976) concluded that drilling and offshore production and pipelines introduce less oil into the environment than do tankers and other oil sources. Tankers are the source of the highest volume of oil spilled (0.016% of the total volume of oil handled), while platforms have the lowest volume of oil spilled (0.006% of the total volume of oil handled).

Budget of Petroleum Hydrocarbons Introduced into the Oceans
(adapted from National Academy of Sciences, 1975)

Source	Input Rate (mta)* Best Estimate	Input Rate (mta)* Probable Range	Reference
Natural seeps	0.6	0.2-1.0	Wilson et al. (1973)
Offshore production	0.08	0.08-0.15	Wilson et al. (1973)
Transportation			
LOT tankers	0.31	0.15-0.4	National Academy of
Non-LOT tankers	0.77	0.65-1.0	Sciences 1975)
Dry docking	0.25	0.2-0.3	
Terminal operations	0.003	0.0015-0.005	
Bilges bunkering	0.5	0.4-0.7	
Tanker accidents	0.2	0.12-0.25	
Nontanker accidents	0.1	0.02-0.15	
Coastal refineries	0.2	0.2-0.3	Brummage (1973)
Atmosphere	0.6	0.4-0.8	Fuerstein (1973)
Coastal municipal wastes	0.3	-	Storrs (1973)
Coastal, Nonrefining industrial wastes	0.3	-	Storrs (1973)
Urban runoff	0.3	0.1-0.5	Storrs (1973), Hallhagen (1973)
River runoff	1.6	-	Storrs (1973), Hallhagen (1973)
TOTAL	6.113		

* mta, million metric tons per annum

ANALYTICAL METHODS

General Procedures

Chemical analysis and characterization of oils has long been carried out by the petroleum industry. However, oils which have been spilled on water undergo numerous changes which make conventional methods (e.g., viscosity, boiling range and flashpoint) useless for fingerprinting. Since no single analytical method has yet been established as fully characterizing an oil, the U.S. Coast Guard Research and Development Center chose four different analytical procedures for their oil identification system. These procedures are infrared spectroscopy, fluorescence spectroscopy, gas chromatography (utilizing both flame ionization and flame photometric detectors), and thin-layer chromatography. If necessary, other methods such as elemental analysis for nitrogen, sulfur, and nickel and vanadium, mass spectrometry, UV spectroscopy and atomic absorption are used to aid in the identification of the oil (Bentz, 1976).

Most of these methods suffer from at least one of two disadvantages, lack of sensitivity or lack of specificity. To study the effects of chronic, low-level pollution it is necessary to choose an analytical method which is capable of detecting and measuring the major components of crude oil. It should also be capable of distinguishing exogenous from endogenous hydrocarbons in living organisms and should be capable of attaining high sensitivity. Infrared spectroscopy lacks sensitivity and is not capable of identifying or quantitating individual compounds in petroleum. Fluorescence spectroscopy is limited to the detection of some aromatic, heterocyclic, and unsaturated compounds, and is also not capable of identifying individual constitutents of crude oil. Thin-layer chromatography has requisite sensitivity, but the resolution is insufficient for the separation of individual compounds.

GC and GC-MS

Gas chromatography (GC) has been demonstrated to be a powerful tool in the analysis of crude oils through the use of n-alkane/isoprenoid ratios and alkane patterns (Jackson et al., 1975). Others have used gas chromatography to identify pollutants on beaches and in water (Adlard et al., 1971; Ehrhardt and Blumer, 1975; Garza and Muth, 1974; Dell'Acqua et al., 1975). With the development of high resolution capillary columns, additional fingerprint materials can be obtained from the detailed pattern of peaks between the n-paraffins (Cole, 1971). In addition, the use of capillary columns leads to greater precision and reproducibility in environmental sample identification as well as the ability to resolve indigenous compounds from petroleum hydrocarbons (Zafiriou, 1973; Overton et al., 1977).

A major disadvantage of GC is that the separated components of mixtures cannot be conclusively identified by this technique. However the use of the mass spectrometer as a gas chromatographic detector allows structural determination as well as sufficient sensitivity for the analytical procedure. GC-MS has been employed in the analysis of river water (Hites and Biemann, 1972), water in San Francisco Bay (Simoneit et al., 1973), and water in the Gulf of Mexico (Ledet and Laseter, 1974). It has been suggested that GC-MS can be used to monitor certain compounds such as pentacyclic triterpanes which are indicators of oil pollution (Dastillung and Albrecht, 1976).

HYDROCARBONS IN PLATFORM DISCHARGES

Underwater venting of waste gases and brine discharges are the major sources of light hydrocarbons. Since the associated gas has been dissolved in the liquid hydrocarbon phase, it contains an equilibrium mixture of aliphatic and aromatic compounds. Gas chromatographic analysis of a vent gas sample revealed compounds as high as C_{15}, while a chromatogram of a produced brine showed that greater than 90% of the C_5 to C_{10} compounds in this sample are aromatic. Measurement of the dissolved C_1 to C_4 hydrocarbons show a 20-fold increase in Louisiana shelf waters over open ocean levels of the light hydrocarbons, while calculations from discharge rates indicate that 450 metric tons of C_5 to C_{10} hydrocarbons are being added to Louisiana shelf waters each year (Brooks et al., 1977).

HYDROCARBONS IN SEAWATER

Pollutant Levels

Organic compounds are introduced into seawater from many and varied sources. The variability in the nature of marine organic matter can provide tags for recognizing specific water masses for long time periods. Blumer (1970) identified the organic compounds present in the pentane-soluble fraction of local near-shore surface water. Straight chain hydrocarbons from C_{14} to C_{33}, with maxima at C_{25} to C_{28}, were reported. No odd-carbon predominance was observed. Isoprenoid hydrocarbons, pristane and phytane, were also represented. Similar results were reported for coastal and open seawaters off the coast of France and west Africa (Barbier et al., 1973). The concentrations in these samples varied from 10 to 140 ppb, with a maxima at n-C_{27} to n-C_{30}. For Atlantic Ocean water, the median concentration of nonvolatile hydrocarbons was 4 ppb with values ranging from 1.3 to 13 ppb (Brown and Huffman, 1976). Concentrations of hydrocarbons in the eastern Gulf of Mexico and the Caribbean Sea ranged from traces to 75 ppb with a maximum n-alkane content between C_{15} and C_{20} (Iliffe and Calder, 1974).

The organic constituents of river water have been identified as normal alkanes (C_{15} to C_{31}), alkyl naphthalenes, alkyl anthracenes or phenanthrenes, pyrene, fluoranthrene, and phthalates with concentrations ranging from 0.05 ppb for pyrene to 1 ppb for diethylhexyl-2-phthalate (Hites and Biemann, 1972). Petroleum ether extracts of San Francisco Bay area water contained 2.5 to 102 ppb of cyclic and acyclic hydrocarbons such as n-alkanes, steranes and unsaturated hydrocarbons (Simoniet et al., 1973).

Most of the organic compounds in water occur either in particulate residues or in the surface microlayer. Particulate petroleum residues have been collected from the Gulf Stream, Sargasso Sea, and the Caribbean Sea, as well as the Mediterranean Sea and the eastern North Atlantic Ocean (Horn et al., 1970; Levy and Walton, 1976). Normal alkanes in surface microlayer samples from the Gulf of Mexico ranged from C_{16} to C_{27}, however the predominant compounds were methyl branched alkanes ranging in chain length from C_{15} to C_{35} and cycloalkanes (Ledet and Laseter, 1974).

Since the hydrocarbons of most marine organisms are dominated by a few compounds (see following sections), it can be expected that seawater containing only biogenic compounds would also have a limited diversity of hydrocarbon composition. However, if the range of hydrocarbons in a water sample is complex, then it is likely that these compounds are petroleum-derived. This conclusion would be substantiated by the presence of aromatic hydrocarbons.

HYDROCARBONS IN PLANKTON

Saturated Hydrocarbons

Hydrocarbons other than squalene are generally trace constituents in marine animals. They may, however, be major components of marine algae. Analysis of the alkane content of 12 species of northeast Atlantic intertidal zone seaweeds, one species of pelagic seaweed, three species of cultured algae, and a mixed marine plankton sample resulted in a hydrocarbon content of 10-120 ppm with an insignificant odd-carbon predominance. All the algae analyzed had a concentration maximum in their alkane profiles at C_{15} or C_{17}, a minimum between C_{19} and C_{21}, and a secondary maximum near C_{27} to C_{30}. Based on this information, the algae were placed in one of two categories depending on their primary concentration maximum. In the red and green algae, n-C_{17} dominated, while in the brown algae, n-C_{15} dominated (Clark and Blumer, 1967).

An algal mat sample from the Texas Gulf coast contained hydrocarbons ranging from n-C_{15} through n-C_{31} with only small amounts above n-C_{23} (Oro' et al., 1967). The major component of the mat samples was n-C_{17}. This compound also dominated in the blue-green algae *Anacystis nidulans*, *Nostoc muscorum*, *Phormidium luridum*, and *Chlorogleae fritschii* as well as in the green algae *Spirogyra* and *Chlorella* (Han *et al.*, 1968 a,b). Samples of blue-green algae and green algae, cultured in the laboratory or collected from seawater, were shown to contain alkanes in the range C_{14} to C_{23} with no odd-carbon dominance if C_{17} is eliminated (Han and Calvin, 1969; Winters *et al.*, 1969; Botello and Mandelli, 1978). However, a few species were reported to contain a bimodal distribution of aliphatic hydrocarbons with maxima at *n*-C_{17} and *n*-C_{27}, and significant amounts of *n*-C_{23}, *n*-C_{27}, and *n*-C_{29} olefins and paraffins (Gelpi *et al.*, 1970).

Terpenoid hydrocarbons, derived from isopentenyl pyrophosphate, have been reported in a wide variety of marine organisms. Pristane (2,6,10,14-tetramethylpentadecane) is the major hydrocarbon in copepods and zooplankton (Blumer *et al.*, 1963; 1964; Clark and Blumer, 1967). Crude pristane has been shown to contain isomeric C_{19} monoolefins, which originate in the phytol digested by zooplankton (Blumer and Thomas, 1965 a,b; Avigan and Blumer, 1968). Di- and triolefinic derivatives of pristane (2,10- and 5,10-dienes and the 2,6,10-triene) were also isolated from zooplankton (Blumer *et al.*, 1969). Phytane and squalene have been reported as algal hydrocarbons in a limited number of cases (Oro' *et al.*, 1967; Gelpi *et al.*, 1970; Halsall and Hills, 1971; Paoletti *et al.*, 1976).

Other branched, saturated alkanes, include the 7- and 8-methylheptadecanes present in blue-green algae (Han *et al.*, 1968a, b; Han and Calvin, 1969).

Based on this background, it has been shown that pelagic *Sargassum* weed were contaminated with petroleum, since samples showed a series of alkanes from C_{16} to C_{30} and phytane (Burns and Teal, 1973).

Alkenes

The monounsaturated alkenes, $C_{15:1}$, $C_{16:1}$, $C_{17:1}$, $C_{18:1}$, and $C_{19:1}$, have been demonstrated to be important components of some phytoplankton (Winters *et al.*, 1969). Three isomeric heptadecenes were isolated from algae, and the double bond locations were established as being in the 3, 5, and 7 positions (Blumer *et al.*, 1971; Youngblodd *et al.*, 1971). Recently it was reported that green algae (Chlorophyceae) contain appreciable amounts of an *n*-C_{27} monoene (Paoletti *et al.*, 1976).

Diolefins were reported to be major components of the algae *Botyrococcus braunii* and *Anacystis montana* with the identification of 1,18-heptacosadiene, 1,20-nonacosadiene, and 1,22-hentriacontadiene (Gelpi *et al.*, 1968; Knights *et al.*, 1970).

However, the predominant hydrocarbons of most marine algae are polyunsaturated, such as the all-*cis*-3,6,9,12,15,18-heneicosahexaene (HEH) (Lee *et al.*, 1970). The compound has been reported in representatives from the algal classes Bacillariophyceae, Dinophyceae, Cryptophyceae, Haptophyceae, and Euglenophyceae (Blumer *et al.*, 1970). A hydrogenation product, *n*-heneicosane, of HEH was found in *Rhizosolenia setigara*, and the corresponding tetraolefin was a minor component of *Thalassioseria fluviatilis* (Blumer *et al.*, 1971).

Compounds related to HEH, 1,6,9,12,15-heneicosapentaene and 1,6,9,12,15,18-heneicosahexaene, have been reported in the brown algae Fucus vesiculosus (Halsall and Hills, 1971). Other polyunsaturated olefins, found in various algae, include the all- cis-4,7,10,13-nonadecatetraene, the all-cis-3,6,9,12,15-nonadecapentaene, the all- cis-3,6,9,12,15-heneicosapentaene, and a compound tentatively identified as cis-1,4,7,10,13,16-nonadecahexaene (Youngblood et al., 1971; Youngblood and Blumer, 1973).

Hydrocarbon Function

Since most hydrocarbons are less dense than seawater, it is possible that these are important in providing buoyancy to marine organisms. For example, squalene which cannot be further oxidized to provide metabolic energy nor quickly eliminated except through the cholesterol pathway has been ascribed such a role (Sargent et al., 1976).

Certain compounds such as n-alkanes and olefins are more abundant in vegetative than in reproductive tissue in phytoplankton. Polyunsaturated hydrocarbons such as HEH, however, occur exclusively in the reproductive tissue suggesting a possible correlation between reproductive chemistry and the olefin content of benthic and plankton marine algae (Youngblood et al., 1973). For example, mature female receptacles of Fucus vesiculosus have a lower polyolefin content than a younger specimen. Also, the polyolefin content of developing receptacles is higher than that of sterile thallus, but it decreases again with increasing maturity of the fruiting bodies suggesting considerable hydrocarbon recycling (Youngblood and Blumer, 1970).

It has also been suggested that the sex ratio of laboratory reared Calanus helgolandicus depends on the composition of algal food (Paffenhofer, 1970). Youngblood et al., (1973) suggested that the percentage of males could be correlated with the predominance of HEH in the algal food fed to the nauplii.

These recent discoveries suggest a deeper involvement of straight chain hydrocarbons in cell biochemistry than was previously considered. However, the mode of biosynthesis or the function of many of these compounds remains unknown.

HYDROCARBONS IN INVERTEBRATES

Biogenic Hydrocarbons

Hydrocarbons isolated from marine organisms grown in water culture under conditions which avoid contamination by petroleum hydrocarbons are not very diverse and have a limited boiling range (n-C_{12} to n-C_{22}) (Farrington and Quinn, 1973). For example, the crustacean Ligia oceanica has surface waxes composed of n-alkanes from C_{14} to C_{33} and pristane (Hamilton et al., 1975). Shrimp and squid from the Gulf of Mexico both contained pristane; however, shrimp had very low concentration of C_{15} and C_{17} paraffins with their maximum concentration at C_{31}. The alkanes C_{15} and C_{17} dominated in the squid samples (Giam et al., 1976). As a part of a baseline study, oysters from Campeche, Mexico were examined for their hydrocarbon content. They showed n-alkanes in the C_{14} to C_{32} range with a predominance of C_{23} and C_{21} in all the samples analyzed (Bottello and Mandelli, 1978). The naturally occurring hydrocarbon content of marine mussels is approximately 0.33% with the major components being pristane, eicosene, and heneicosahexane (Lee et al., 1972).

In contrast to the odd carbon dominance exhibited for representatives of the phyla Mollusca and Arthropoda, the n-alkane distributions of Porifera (sponges) and Coelenterata (corals) revealed very little odd-number preference (OEP) in the C_{24} to C_{34} range (Koons et al., 1965). Many of these organisms are identified in the algal mat associated with barnacle shells such as those seen on the legs of offshore production platforms (Fotheringham, 1977; Martin, 1978).

Environmental Indicators for Pollution

Mussels have been proposed as a test organism for monitoring long-term hydrocarbon pollution in marine waters. *Mytilus edulis* rapidly assimilated labeled hydrocarbons or fuel oil and, after transfer to seawater, they discharged most of the hydrocarbons (half-life: 2.7 to 3.5 days) (Lee et al., 1972; DiSalvo et al., 1975; Fossato and Canzonier, 1976). Oysters (*Crassostrea virginica*), clams (*Rangia cuneata*), fish (*Fundulus similus*), and shrimp (*Penaeus aztecus*) also accumulated a wide variety of hydrocarbons when exposed to oil-contaminated seawater. After return to oil-free water, these animals released the accumulated hydrocarbons from their tissues. However shrimp and fish, which can metabolize hydrocarbons, released them more rapidly than clams or oysters, which apparently lack the detoxifying enzymes (Stegeman and Teal, 1973; Neff et al., 1976).

Molluscs from various locations have been examined for their hydrocarbon pollutant content. Mussels (*Mytilus edulis* and *M. californiaus*) from Puget Sound and Strait of Juan de Fuca, clams (*Mercenaria mercenaria*) from Narragansett Bay, and oysters (*Crassostrea virginica*) from Galveston Bay all exhibited a complex mixture of hydrocarbons which resembled the distributions found in crude oil as well as the abiogenic acyclic and aromatic compounds (Ehrhardt, 1972; Clark and Finley, 1973; Farrington and Quinn, 1973). Other molluscs have been shown to contain polycyclic aromatic hydrocarbons or to release these compounds after exposure to clean water (Bravo et al., 1978; Dunn and Stich, 1976).

HYDROCARBONS IN VERTEBRATES

Gas chromatographic analysis of herring oil revealed the presence of aliphatic hydrocarbons from C_{14} to C_{33}, with high concentrations of n-C_{17}, n-C_{19}, n-C_{25}, n-C_{27}, and n-C_{29}. The terpenoids pristane and squalene were also present (Lambertsen and Holman, 1963). Pristane and its olefinic isomers have been identified in the oils of various freshwater and marine fish such as *Pomolobus* sp. (alewife), *Cetorhinus maximus* (basking shark), *Gadus* sp. (cod), and *Aplodinotus grunniens* (sheepshead), as well as in the sperm whale (*Physeter catodon*) (Blumer and Thomas, 1965; Blumer et al., 1969; Ackman, 1971). The hydrocarbon patterns of various fish from the Gulf of Mexico have also been examined. The sand seatrout, longspine porgy, and the flounder have bimodal distributions of aliphatic hydrocarbons and a high pristane content. These benthic fish oils are composed primarily of the n-alkanes C_{15}, C_{17}, and C_{25} through C_{35}. On the other hand, the wenchman has n-C_{15} and n-C_{17} as the dominant hydrocarbons with trace amounts of other compounds (Giam et al., 1976).

Hydrocarbons in vertebrates are thought to arise from their diet (Blumer, 1967). This is evident in studies of wild codling which were fed cod liver oil containing crude oil. Within six months, the alkane pattern in the liver lost its marked odd-carbon preference, and the maximum decreased from C_{29} or C_{31} to C_{26} (Hardie et al., 1974). It has been postulated that hydrocarbons are formed by the decarboxylation of fatty acids which would account for the dominance of odd-chain hydrocarbons. However, a biosynthetic pathway for the formation of hydrocarbons of chain lengths greater than C_{26} has yet to be found in marine organisms (Sargent et al., 1976).

Hydrocarbons in vertebrates have several postulated functions. For example, large amounts of squalene in shark livers can serve to bring these animals close to neutral buoyancy. In addition, squalene serves as the precursor of the biologically important steroids, except in the shark which lacks the enzyme squalene-2,3-epoxidase. Also, the concept has emerged that lipid material may provide thermal insulation as in the external layer of blubber in the cetaceans (Sargent et al., 1976).

HYDROCARBONS IN SEDIMENTS

Aliphatic Hydrocarbons

Geologists have studied sedimentary material from various locations in their quest for the origin of petroleum. Examination of recent marine sediments from the Gulf of Mexico revealed the presence of normal paraffin hydrocarbons ranging from C_{12} to C_{32}. The dominant hydrocarbons were nonacosane (C_{29}) and hentriacontane (C_{32}), and the muds showed a marked odd-carbon preference (Stevens et al., 1956; Evans et al., 1957). Similar distributions have been seen in sediments from San Francisco Bay, California (Kvenvolden, 1962), Tarpulin Cove, Massachusetts (Clark and Blumer, 1967), Lake Zug, Switzerland (Giger et al., 1974), and Terminos Lagoon, Campeche Mexico (Bottello and Mandelli, 1978), in addition to lacustrine and subtropical lagoonal/tidal flat sediments (Brooks et al., 1976). Some recent sediments do not contain phytane, suggesting a geochemical origin for phytane (Blumer and Snyder, 1965).

While sediments contain a marked odd-carbon preference, source rocks and shales from various ancient sediments have an OEP ratio close to unity (Bray and Davis, 1961; Meinschein, 1961). Examination of source rocks has led to the postulate that petroleum is generated by thermal, nonbiological processes, and that it migrated through faults and fractures (Philippi, 1965). Examination of aliphatic hydrocarbons and fatty acids in a salt marsh, however, showed a marked change in the OEP values from 3.2 in the surface sediments to 1.1 in the bottom core (24 cm). This was postulated to occur through in situ microbial activity by modification of fatty acids and deposition of branched chain compounds (Johnson and Calder, 1973).

Sediment samples taken from various locations which have a terrigenous input can be compared to samples from locations with a marine input. For example, cores from the continental slope of the eastern Atlantic showed a low OEP ratio in the uppermost 15 cm (1.5) suggesting a crude petroleum input, but the lower two sections showed ratios similar to those seen in terrestrial aquatic sediments (Gaskell et al., 1975). Sediments deposited in a lake after 1880 showed a marked increase in petroleum-type hydrocarbons (Wakeham and

Carpenter, 1975). Similarly, sediments from Boston Harbor, Massachusetts and Lake Zug, Switzerland which have areas of predominantly petroleum input and areas of predominantly biogenic input can be easily contrasted with respect to their hydrocarbon content (Shaw, 1973; Giger *et al*., 1974). In the Gulf of Mexico, samples from the Mississippi coast have an even distribution of alkanes, while sediments from the Florida coast contain mainly odd-carbon number high molecular weight alkanes (Gearing *et al*., 1976; Lytle and Lytle, 1976).

Aromatic Hydrocarbons

Analysis of sediment samples has demonstrated a complexity of the polycyclic aromatic hydrocarbon (PAH) fraction. The principal series, unsubstituted hydrocarbons and alkyl derivatives, occur over a wide molecular weight range. The minor series, interpreted as naphthenologs and thienologs of the basic PAH series, also cover a wide carbon number range. Several possible origins for the PAH mixture have been postulated. These included biochemical, early diagensis and pyrolysis at various temperatures. A biochemical origin for the sedimentary PAH fraction would lead to simple mixture of compounds which are not chemically complex. However, the low abundance of linear systems (anthracene, *etc*.), the predominance of unsubstituted hydrocarbons, the thienologs and the great overall complexity are more characteristic of a thermal origin. Early diagensis would favor a high degree of alkyl substitution and would not be very likely to be deposited widely in the environment. Pyrolysis at high temperatures (automotive engines and domestic heating) favors unsubstituted aromatics. Therefore a pyrolytic origin at intermediate temperatures was suggested. A wood pyrolysate had molecular weight distribution patterns similar to those seen in sediment samples (Giger and Blumer, 1974; Youngblood and Blumer, 1975; Blumer and Youngblood, 1975; Blumer *et al*., 1977).

Cores from two locations in the Grosser Ploner Sea (Germany), one obtained near a railway station and the other from a virgin area of beach showed a substantial increase in PAH content after 1920 (Grimmer and Bohnke, 1975). Examination of cores from Buzzards Bay, Massachusetts revealed that the concentrations of PAH from sections dated after 1910 greatly exceed those concentrations from sections dated around 1850 (Hites *et al*., 1977). All the authors concluded that the major source of PAH in these locations was anthropogenic combustion.

HYDROCARBONS IN BACTERIA

Uncharacterized or partially characterized mixtures of alkanes have been reported for *Sarcina lutea* (Albro and Huston, 1964), *Desulfovibrio desulfuricans* (Davis, 1968), *Vibrio marinus* (Oro' *et al*., 1967), *Escherichia coli*, *Micrococcus lysodeikticus*, *Rhodopseudomonas speroides*, and *Rhodospirillum rubrum* (Han *et al*., 1968), and *Pseduomonas shermanii*, *Clostridrium*, *Chlorobrium*, and *Rhodomicrobium* (Han and Calvin, 1969). It was generalized that most photosynthetic bacteria contain predominantly medium length (C_{14} to C_{20}) hydrocarbons, while non-photosynthetic bacteria have higher molecular weight (C_{26} to C_{30}) hydrocarbons (Albro, 1976). The hydrocarbons present were usually alkanes, monounsaturated alkanes with a double bond in the middle, or *iso* or *anteiso* methyl branched alkanes (Albro, 1969, 1976).

Hydrocarbons in bacteria are presumed to be biosynthesized from fatty acids *via* one of two postulated mechanisms. The "Head-to-Head" condensation involves the condensation of two molecules of fatty acids, one of which is decarboxylated in the process:

$$RCH_2COOH + R'CH_2COOH \longrightarrow CO_2 + RCH_2COCH_2R' \longrightarrow RCH_2CHOHCH_2R'$$

$$RCH_2CHOHCH_2R' \longrightarrow RCH_2CH{=}CHR' \longrightarrow RCH_2CH_2CH_2R'$$

The second mechanism, the "Elongation-Decarboxylation" pathway involves the elongation of a fatty acid chain *via* the addition of acetate, oxidative decarboxylation and reduction. Aliphatic hydrocarbons (C_6 to C_{20}) are presumed to be oxidized *via* a primary alcohol and an aldehyde to yield the corresponding fatty acid. Intermediates involving hydroperoxides or 1-alkenes and 1,2-epoxide derivatives have been proposed (Albro, 1969).

MATERIALS AND METHODS

MATERIALS

All organic solvents (except diethyl ether) were Mallinckrodt (St. Louis, Mo.) "Nanograde" quality. Diethyl ether was Mallinckrodt "reagent grade" quality. Silica gel (60-200 mesh) for chromatography, obtained from J. T. Baker (Phillipsburg, N.J.), was heated at 110° for at least 24 hr prior to use. Hydrocarbon standards were purchased from Applied Science Labs (State College, Pa.) or from Chem Service (West Chester, Pa.) and deuteriated hydrocarbons from Merck (Elmsford, N.Y.).

SAMPLE COLLECTION

Discharged Brine

Samples of discharged brine (Fig. 1) were collected directly in 250 ml or 1 l wide-mouth glass bottles fitted with ground glass stoppers. Samples were frozen immediately after collection; they were maintained at -20° to minimize bacterial growth.

Seawater

Water samples were collected by Nansen bottle or by divers using 1 l sample bottles. The water depth in the area is 20 m. Surface water samples were collected by Nansen bottle, stainless steel bucket, or glass bottles from the bow of the boat to minimize contamination. Samples for the platform study were obtained using a Brinkmann sampler equipped with 1 l Wheaton bottles which were fitted with Teflon-lined screw caps. All of the samples were frozen in glass bottles and were maintained at -20° until analysis.

Plankton

Subsurface samples were obtained using paired 61 cm diameter bongo nets with mesh size of 0.333 and 0.505 mm. Timed double oblique tows were performed to examine the depth strata equally from the surface to about 1 m off the bottom. A neuston net with a mouth opening of 0.5 by 1.0 m and a mesh size of 0.505 mm was used to collect surface samples. All the samples were frozen in seawater in glass jars on-board ship and were maintained in that state until analysis.

Fish

Samples were obtained either by trawling with a 12 m nylon mesh semiballoon shrimp trawl, by trapping with modified sablefish traps, or by spearing. Samples were placed in large glass bottles or were wrapped in aluminum foil and placed in cotton sacks before freezing. Samples were maintained at -20° to minimize bacterial contamination.

Shrimp

Shrimp samples were collected using a 12 m nylon mesh semiballoon shrimp trawl. Shrimp were sorted by species and were wrapped in aluminum foil or placed in glass jars. Samples were maintained at -20° to minimize contamination.

Benthic Organisms

All samples were collected by divers from the surface of the sediments in the study area. Organisms were frozen in cotton sacks and maintained in that state until analysis.

Barnacles

All samples were obtained by divers and were placed in cotton sacks for storage at -20° until analysis.

Sediments

Sediment samples collected during 1976 were obtained using a 15 cm coring device or a ponar grab. Additional samples, collected during 1977, were scooped directly into 250 ml glass jars by divers. Sediments were frozen immediately after collection and were maintained in this state until analysis.

Bacteria

Bacteria samples, obtained from cultures of sediments in the vicinity of the production platforms, were generously supplied by Dr. Ronald Sizemore in solvent-rinsed scintillation vials.

Oil and Condensate

Oil and gas condensate were collected in 250 ml bottles fitted with ground glass stoppers.

Miscellaneous

Vessel fuel was collected from the work ship, Gus III. Biocide and surfactant samples were obtained from the production platforms, as were samples of the skim tank oil and of water from the brine separator drip pan. A sample of water from the sewage discharge pipe on the living quarters platform was also obtained.

Bulk Brine Sample

Four gallons of discharged brine were collected from the production platform in 1 gal solvent bottles.

EXTRACTION PROCEDURES

Discharged Brine

Samples were acidified to pH 2 and n-[$^{2}\mathrm{H}_{42}$]eicosane and n-[$^{2}\mathrm{H}_{66}$]dotriacontane (internal standards) were added to the discharged brines. Sample bottles were rinsed with 100 ml of cyclohexane, and the rinse was used to extract the sample, either by shaking in a separatory funnel (1976-77) samples or by tumbling on a modified rock polisher for 24 hr (1977-78) samples. The cyclohexane was concentrated using a Buchi/Brinkmann Rotavapor R rotating evaporator before column chromatography. After extraction, sulfur in the brine sample was vacuum filtered and weighed after drying at room temperature.

Seawater

Water samples were analyzed using the same procedure as the discharged brine samples.

Plankton

No attempt was made to separate and analyze the individual species; a copepod (*Acartia tonsa*), the sergestid shrimp (*Lucifer faxoni*), and a chaetognath (*Sagitta tenuis*) were among the major species obtained (Fotheringham, 1976; Fotheringham and Brunenmeister, 1975). The extraction procedure was modified from that described by Warner (1976). n-[$^{2}\mathrm{H}_{42}$]-Eicosane and n-[$^{2}\mathrm{H}_{66}$]dotriacontane were added to 10 g of plankton. The sample was homogenized using a Brinkmann PT 10-35 Polytron power unit equipped with a PT 20ST generator. The homogenate was transferred to a 50 ml centrifuge tube, and NaOH solution (6 ml, 4 *M*) was added. The sample was saponified at 110° for 2 hr. The saponified material was cooled in the freezer before extraction with 15 ml and then 10 ml of diethyl ether. Each time the supernatant layer was drawn off after centrifugation at 2000 r.p.m. for 10 min. The combined extracts were dried over anhydrous sodium sulfate (1 g), and the solvent was evaporated using the rotating evaporator.

Fish

In the laboratory, a sample of dorsal flesh (including skin, subcutaneous fat, and muscle tissue) was excised from each specimen using a degreased scalpel and scissors. With the exception of the smaller fish (*Stenotomus caprinus*, *Micropagon undulatus*, *Peprilus burti*, *Scorpaena calcarata*, *Symphurus plaguisa*, *Prionotus ophryas*, and *Atharichthys spilopterus*), livers were also analyzed. Whole body analysis was performed on samples of *Blennius marmoreus* and *Hypleurochilus geminatus*. Analytical procedures were similar to those used for plankton except that 10-20 g of flesh and 2-5 g of liver were analyzed.

Shrimp

The same procedure was used for the analysis of shrimp and plankton except that 5-20 g of shrimp were analyzed.

Benthic Organisms

Mollusc samples, such as *Pleuroploea gigantea*, *Murex fulvescens*, Paguridae and *Fasciolaria hunteria*, were extracted from their shells, and the muscle dissected with a degreased scalpel and scissors. Hydroid and Alcyonaria samples were cut into small pieces with degreased scissors. Extraction was similar to the plankton procedure except that 2-20 g of sample was used.

Barnacles

Tissue samples were obtained by separating the flesh from the shells with degreased pliers. The same procedure was used for the analysis of barnacles tissue and plankton, except that 15-35 g of sample was analyzed.

For shell samples obtained during the period June, 1976 to May, 1977, extraction was performed by placing 50-100 g of shell in a 45 by 130 mm glass extraction thimble. Appropriate internal standards were added, and the shells were extracted with cyclohexane (300 ml) for 6 hr in a modified Soxhlet apparatus (Toe-Pre 807). The extract was reduced in volume prior to column chromatography. A different procedure was employed for the extraction of samples collected after June, 1977. The shells were tumbled with cyclohexane (100 ml) in a 1 l glass bottle fitted with a Teflon-lined screw cap for 24 hr on a modified rock polisher (Scott-Murray, Seattle, Wash.). The cyclohexane solution was decanted and was reduced in volume prior to column chromatography.

Sediments

For the 1976 samples, approximately 100 g of sediment was transferred to a 300 ml lyophilization flask (Virtis F-121) and was freeze-dried (New Brunswick Freeze Drier). Standards were added to the dried sample after transfer to a 45 by 130 mm glass extraction thimble in a modified Soxhlet apparatus. The sample was extracted with cyclohexane (300 ml) for 6 hr, and the extract was reduced in volume before column chromatography. For the 1977 samples, the procedure used for the barnacle shell samples collected after June, 1977 was employed.

Bacteria

Bacteria samples were suspended in 5 ml of deionized water and appropriate amounts of internal standards were added. The samples were sonicated until viscous with a Heat Systems Ultrasonics probe. The homogenate was transferred to a 50 ml centrifuge tube, and the extraction proceeded as described for the plankton.

Oil and Condensate

Oil and condensate samples were analyzed by placing 10 µl (approx. 1 mg) of sample and 10 µl of standards in 1 ml of cyclohexane. This extract was used for column chromatography.

Miscellaneous Samples

Vessel fuel, surfactant, biocides, and skim tank oil samples were analyzed using the same procedure as the oil and condensate samples. Water samples from the brine separator drip pan and the sewage discharge pipe were analyzed using the same procedure as discharged brine samples.

Bulk Discharged Brine

The following extraction procedure was used for each bottle. 250 ml of cyclohexane was added to the bottle, and it was shaken. Half the liquid was poured into a separatory funnel, and the lower (aqueous) phase was drained into a second bottle. This was repeated with the second half of the brine liquid. The first sample bottle was rinsed with 125 ml of cyclohexane, and the washings were transferred to the second bottle. The rinse procedure was repeated with another 125 ml of cyclohexane which was also added to the second bottle. The second bottle was re-extracted with 250 ml of bottle washings. The organic phase of both extracts was combined in a beaker, and the sulfur was allowed to settle. The cyclohexane fraction was reduced in volume in the rotating evaporator, and the sulfur was saved. Then, 250 ml of $CHCl_3$:MeOH (2:1) was added to the sample bottle. After shaking, half the liquid was poured into a separatory funnel. Since the chloroform did not separate from the brine, all of this liquid was discarded and the second half of the liquid was poured into the separatory funnel. The lower (organic) phase was reduced in volume, and the upper (aqueous) phase was discarded.

COLUMN CHROMATOGRAPHY

Samples were fractionated on a 1 by 20 cm column packed with deactivated silica gel. The silica gel column was washed with cyclohexane (100 ml), and the sample was applied. "Alkanes" were eluted in cyclohexane (40 ml), followed by benzene (40 ml) for elution of the "aromatics." The volume of the eluants was reduced to 50 µl, first by the rotating evaporator and then under a stream of nitrogen on a hot plate, before gas chromatography or combined gas chromatography - mass spectrometry.

GAS CHROMATOGRAPHY

Use of Internal Standards

Deuteriated hydrocarbons were added to all samples prior to analysis so that quantitative data would not be impaired by variations in sample recovery, GC injection volume, or instrument parameters. In most instances a mass spectrometer is required as the gas chromatographic detector to differentiate between the labeled and unlabeled species (Sweeley *et al.*, 1966). Fig. 2 shows a chromatogram obtained for a mixture of *n*-alkanes ($C_{12}H_{26}$ to $C_{36}H_{74}$), together with three perdeuteriated *n*-alkanes ($C_{16}D_{34}$, $C_{20}D_{42}$, and $C_{32}D_{66}$). In each instance, the deuteriated compound is completely separated from the corresponding unlabeled *n*-alkane. Thus, no mass spectrometer is required to differentiate these pairs of compounds, even when conventional packed gas chromatographic columns are employed.

The various compounds employed for hydrocarbon analysis were n-[$^2H_{42}$]eicosane, n-[$^2H_{66}$]dotriacontane, [$^2H_{10}$]pyrene, [$^2H_{12}$]benzanthracene, [$^2H_{10}$]-1-methylnaphthalene, [$^2H_{10}$]-2-methylnaphthalene, and [$^2H_{12}$]benzo[a]-pyrene. An appropriate quantity of the deuteriated hydrocarbons was added to the sample before analysis. For example, 2 µl of a 0.1% solution added to 1 l of seawater afforded a concentration of 2 ppb.

Instrument Conditions

Gas chromatography was performed on Perkin-Elmer 3920B instruments equipped with flame ionization detectors and temperature programmers. The samples collected prior to June, 1977 were examined using silanized glass columns (2 m by 2 mm I.D.) containing 1% OV-1 on Supelcoport (100-120 mesh), programmed from 100 to 300° at 4° per min. The remaining samples were examined using a 30 m glass capillary column (purchased from Perkin-Elmer) coated with OV-101, programmed from 90 to 270° at 2° per min. The injector and detector temperatures were 250 and 300°, respectively, for all analyses.

GAS CHROMATOGRAPHY - MASS SPECTROMETRY

Identification and Confirmation

Representative samples were examined by combined gas chromatography - mass spectrometry to verify the identities of compounds characterized by GC. A Hewlett-Packard 5992A instrument was used for this purpose. This instrument was equipped with a silicone membrane separator and 1 m by 2 mm I.D. silanized glass column containing 3% OV-17 on Gas Chrom Q (100-120 mesh) programmed from 90 to 270° at 4° per min. Spectra were acquired every 2 seconds, but only those from the apices of gas chromatographic peaks were stored on magnetic tape. Total ion and selected ion chromatograms were produced in real time on a line printer, and programs were available for a full range of data manipulation procedures.

Sulfur Screening

An appropriate quantity of sulfur-34 was added to sediment samples prior to analysis. Since sulfur-32 does not separate from the internal standard, the mass spectrometer was used as the gas chromatographic detector. Fragment ions of sulfur [m/e 64, 66, and 68 (Fig. 3)] were monitored at 230°. A sum of the monitored ion abundances and a selected ion chromatogram were obtained in real time, while the chromatograms for each monitored ion were recorded on tape. Programs were available for the display of the monitored ion abundances and for a full range of data manipulation procedures.

Summary

The integrated analytical procedure is illustrated for sediment samples in Fig. 4.

RESULTS AND DISCUSSION

Analytical data are given for n-alkanes with 12 to 36 carbon atoms per molecule. Those of lower molecular weight were too volatile for quantitative recovery, while n-alkanes with more than 36 carbon atoms per molecule were not detected. Pristane and phytane were the only branched alkanes observed in any appreciable concentrations. The term "total alkanes" refers only to those compounds mentioned in this paragraph.

PLATFORM DISCHARGES

Oil and Condensate

Oil and condensate obtained from each production platform were examined (Tables 1-3).

The alkane composition of the crude oil is consistent with reports on the composition of other crude oils (Smith, 1968). Alkanes from C_{12} to C_{36} comprise approximately 18% of the oil, and they show a decreasing concentration with increase in chain length and an OEP average of 1.02. The n-heptadecane/pristane ratio and the n-octadecane/phytane ratio, often used as indicators for the source of oil, are 0.90 and 2.44 respectively. The condensate contains a lower concentration of alkanes in the C_{12} to C_{36} region than the crude oil (approximately 14%), however the condensate contains larger amounts of the lighter alkanes. The n-heptadecane/pristane ratio is 1.30, and the n-octadecane/phytane ratio is $3.\bar{3}3$. The difference between these ratios and those found for crude oil probably reflects the greater volatility of the C_{17} and C_{18} n-alkanes, compared with that of the C_{19} and C_{20} branched alkanes. Crude oil and condensate from both platforms are of similar composition.

Discharged Brine

Twenty-eight discharged brine samples were collected in 1976-78. Since this is the major discharge from the production platforms, these samples were examined in order to provide information about compounds being discharged into the environment. Other samples from the skim tank and brine separator drip pan were examined for alkane content.

Constituents. In addition to the n-alkanes and the isoprenoids previously mentioned (pristane and phytane), a number of aromatic compounds have been identified in the "aromatic" fraction of discharged brine samples. These include (in decreasing order of concentration) ethylbenzene, a methylethylbenzene, naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, an ethylnaphthalene, styrene, and a methylvinylnaphthalene. This fraction was also found to contain a relatively high concentration of squalene, an indication of the existence of microorganisms in the brine separator tank.

Alkanes. The n-alkane distribution in the discharged brine is somewhat different from that seen in the crude oil and condensate samples. The alkanes detected range from C_{12} to C_{34}, with a maximum concentration of 12.11 ppm and a mean concentration of 3 ppm, which corresponds to 67 ppm and 16.5 ppm, respectively of total oil. The legal limit for the discharge of oil in brine is 50 ppm. Therefore, an occasional brine sample will exceed the limit, but most are well below the limit. Since the mean daily rate of discharge of brine in the field is approximately 200 bbl (31,800 l), the mean rate of discharge of alkanes per day is 95 g. The OEP values for the n-alkanes in the brine range from 0.58 to 1.52 with an average value of 0.99. The low OEP value (IX) was due to the dominance of n-C_{18} and n-C_{20}, while the value (XVI) was due to the high concentration of n-C_{13}. The n-heptadecane/pristane values for the discharged brine range from 0.89 to 1.25 (mean, 1.05), while values for the n-octadecane/phytane ratios range from 1.0 to 5.26 (mean, 2.44). The average ratios are similar to those of Buccaneer crude oil, but many of the individual values are somewhat different. These ratios are often used to identify sources of pollution, yet such a disparity in figures is unreliable in providing identification of samples, especially when weathering has occurred.

Most of the discharged brine samples exhibited concentration maxima between n-C_{13} and n-C_{23}. It is possible that differences in maxima are due to preferential evaporation of lighter alkanes. Samples collected at 21°C from platform B on March 8, 1977 exhibited concentration maxima at C_{12}-C_{15} and an average concentration of 6.2 ppm (Fig. 5), whereas those collected at 30°C on the same day from platform A exhibited concentration maxima at C_{16}-C_{23} and an average concentration of 570 ppb (Fig. 6).

Sutton and Calder (1974) reported the solubilities of various n-alkanes in seawater as being less than 3 ppb. For example, dodecane was soluble at a concentration of 2.9 ppb, while octadecane and eicosane were only soluble at a concentration of 0.8 ppb. These values were exceeded in many of the samples analyzed. (In sample XVII, for example, dodecane was present in a concentration of 1.1 ppm, while heptadecane was present at a concentration of 237 ppb.) It is most likely that these compounds are accommodated in micellar suspensions rather than present in solution; Peake and Hodgson (1966) have shown that alkanes of higher molecular weight may be accommodated as colloids at concentrations up to 0.1%.

Sulfur, Sulfide, and Sulfate. All but two of the discharged brine samples contained visible sulfur in concentrations from 0.006% to 0.12% (Table 38). If the average sulfur concentration is 0.046%, and the mean rate of brine discharge is 200 bbl day^{-1} (31,800 l) then approximately 15 kg of sulfur are discharged daily from the production platforms. Compared to the 95 g discharge of alkanes, this makes sulfur the major oil production contaminant. If oil is adsorbed onto the sulfur particles, then this may provide a method for distributing contamination throughout the oilfield. In addition, the presence of sulfur in sediments may encourage the growth of sulfur-oxidizing bacteria, a basic component of the food web.

Sulfate is also present in the discharged brine in concentrations ranging from 9.5 to 57 ppm (mean, 28.6 ppm) (Table 49). Since these concentrations are considerably less than values for seawater (0.27% sulfate in seawater of 3.5% salinity), sulfate is not an important oil production related contaminant (Sumich, 1976). Sulfide was detectable in only two brine samples, XXIV and XXV, at concentrations of 34 and 0.6 ppm respectively (Table 50). Since these samples were analyzed shortly after collection, it is possible that hydrogen sulfide in other samples decomposed during storage through the following reaction:

$$8H_2S + 4O_2 \longrightarrow 8H_2O + S_8$$

Carcinogens. Naphthalenes are the major high-boiling aromatic hydrocarbons that transfer from oils into water and consequently can contact marine organisms. Naphthalenes are readily absorbed by the organisms but slowly depurated (Neff and Anderson, 1975). As a consequence of their enhanced availability, high toxicity, rapid uptake and slow depuration, naphthalenes were determined in various samples. The concentration of 1- and 2-methylnaphthalenes in discharged brine samples ranged from 8.6 to 167 ppb (Table 39). The average concentration (43 ppb) is similar to that reported for seawater extracts of Kuwait crude oil (33 ppb) (Boyland and Tripp, 1971). The values for discharged brine probably do not represent solubilities, but instead reflect the amount of methylnaphthalenes in micellar droplets within the water.

While benzo[a]pyrene is "practically insoluble" (Merck Index, 1976), it is also present in trace amounts in discharged brine samples (0.5 to 11 ppb; mean, 2 ppb). Benzo[a]pyrene is a "potential human carcinogen" (Merck Index, 1976), and its presence in marine organisms which may be used for human consumption has profound environmental implications.

Biocides and Surfactants. In order to control the growth of bacteria (which produce corrosive metabolites) in the brine separators, bacteriocides are added to the tanks on a regular basis. The biocides used on the Shell platforms contain glutaraldehyde (K31) or an alkyldimethylbenzyl chloride (KC14 or KM7) (Voss, 1977). Examination of samples of K31 and KC14 revealed only trace amounts of n-alkanes (less than 2 ppm) (Table 26). In addition, a surfactant is used in the brine separator tanks to disperse the oil. The composition of the brand used is unknown. The sample examined contained only trace amounts of n-alkanes (3.26 ppm). These samples do not contribute appreciably to the amount of hydrocarbons in the oil, since they are diluted considerably after addition to the brine separator tanks.

Miscellaneous Samples. After separation of the produced water and oil, the produced water flows to "skim tank" vessels where most of the remaining petroleum products are separated and returned to the oil stream flow. Oil from the skim tank contained 13.8% n-alkanes with an OEP value of 1.18. It showed the typical pattern of decreasing concentrations for the alkanes. The n-heptadecane/pristane ration was 1.28 while the n-octadecane/phytane ratio was 3.33, similar to the values for Buccaneer crude oil (Table 27).

Any overflow or leak from the brine separators is contained by a brine separator drip pan. Water from this pan contained 35.3 ppb of n-alkanes. Unlike the oil samples, the water did not contain a decreasing alkane content; instead it exhibited a petroleum hump from C_{21} to C_{31} with a maximum at C_{26}. This distribution is due to extensive weathering of the oil hydrocarbons in the pan, which results in the evaporation of the lighter components. While samples of rainwater runoff have not been collected from below the platform, it might be anticipated that samples from gutters or drip pans would exhibit hydrocarbon concentrations and profiles similar to those of the brine separator drip pan sample.

Sewage Discharge

The major discharge from the quarters platform is the wastewater from the sewage treatment plants. Examination of a sample from the discharge pipe showed that it contained 47.3 ppb on n-alkanes, most of which was in the range C_{15} to C_{20}. The OEP value was 0.59, while the n-heptadecane/ pristane ratio was 4.0, and the n-octadecane/phytane ratio was 14.3. These values indicated that the major source of these hydrocarbons is not Buccaneer crude oil. However these profiles do not resemble the profiles of hydrocarbons from municipal wastewater treatment plants. These latter samples exhibited an unresolved "hump" indicative of petroleum pollution, and an alkane profile similar to one obtained from automobile crankcase oils (Farrington and Quinn, 1973b). It is likely that many of the hydrocarbons in the sewage effluent from the quarters platform are biogenic (bacterial or fecal, for example).

Summary

Even though the oil and brine have been in contact for many years, the composition of some of the brine samples does not resemble that of the crude oil. This limits the utility of indicators such as OEP values and n-heptadecane/pristane and n-octadecane/phytane ratios. The discharge of various oil production contaminants varies from 15 kg of sulfur to 523 g of oil. Other contaminants include inorganic ions such as sulfide and sulfate, as well as low molecular weight aromatics. Benzo[a]pyrene and methylnaphthalene have been detected in most discharged brine samples. The hydrocarbons content of the other major platform discharge, the sewage pipe, does not resemble crude oil, but seems to be composed of bacterial and fecal alkanes.

SEAWATER

A total of 122 water samples were collected from the study area. The majority of these were surface and bottom samples which were obtained in order to determine if there were hydrocarbon concentration gradients, and if so, the area that the gradients encompass. Additional samples were collected around a production platform in order to determine the distribution of alkanes within the immediate vicinity of the brine discharge. (Tables 4-6)

Platform Study

Seventeen water samples were collected from all sides of production platform B. Of these, four (CXV, CXVII, CXVIII, CXX) contained more than 45 ppb of hydrocarbons with a range from n-C_{17} to n-C_{29} and a maximum at n-C_{18} or n-C_{17}. The OEP values ranged from 0.85 to 1.79. The n-heptadecane/pristane values for the samples were 0.75 and 0.8, and the n-octadecane/ phytane values were 0.82 and 0.57. These values are indicative of slight weathering of the lower molecular-weight alkanes. Alkanes were found in samples collected from the west, north, and east sides of the production platform. While the current that day was in an easterly direction, the wind was blowing from the south. It is possible, therefore, that in the immediate vicinity of the production platforms, the hydrocarbon distribution is influenced by wind direction rather than current direction.

Three samples (CXV, CXVI, CXVII) contained 1- and 2-methylnaphthalene. One sample (CVII) contained 12.7 ppb of benzo[a]pyrene and a further eight (CIX, CXIV, CXV, CXVI, CXVII, CXIX, CXXI, CXXII) had trace amounts of benzo[a]pyrene.

Surface Water Samples

Samples I and II were collected by divers below the brine discharge pipe at platform A. As might be expected, alkane levels were highest at the surface. In both samples, the n-heptadecane/pristane and n-octadecane/ phytane ratios were about 1.2 and 3.7, respectively. These ratios approximate those obtained for brine samples. The surface sample (I) exhibited a typical "petroleum" distribution in the region C_{12} to C_{21}, with concentrations of n-alkanes decreasing with chain length. Due to the weathering of the lighter alkanes, the concentration maximum for the mid-depth sample (II) is at C_{16}. There is a bimodal distribution of n-alkanes in the mid-depth sample with a second, and more pronounced, concentration maximum at C_{32}. The n-alkanes in the region C_{26} to C_{37} exhibit no odd-even preference, so it is probable that they are of bacterial origin (Davis, 1968; Albro, 1976).

Surface samples (IV, VIII, X, XI) collected randomly in June and July, 1976 showed alkane concentrations from 1.2 to 24.8 ppb and contained evidenced that these alkanes were petroleum-derived. There was a "petroleum" distribution in the region from n-C_{15} to n-C_{24} with a maximum in all the samples at n-C_{17}.

During August 31 and September 1, 1976, water samples were collected along a transect running from a point 10 km SW of the center of the oilfield to a point 10 km NE (Fig. 7). Alkane concentrations were higher in the SW (42.8 ppb) and NE(33.7 ppb) ends of the transect than near the center of the oilfield. This was contrary to expectation, but it may merely reflect the variation in the concentration of alkanes in brine discharged from the production platforms. The C_{15} to C_{25} alkanes can be classified as petroleum derived, but it should be noted that these samples also contained smaller amounts of C_{26} to C_{36} alkanes, of apparent bacterial origin, with concentration maxima around C_{32} (Figs. 8, 9).

On September 23, 1976 additional samples were collected at five locations around the oilfield: 20 km NW (XXXV), at the center of the oilfield (XXXVII), 10 km NE (XXXIX), 10 km SW (XLI), and 20 km SE (XLIII). All these samples contained less than 0.53 ppb of alkanes, the majority of which was the biogenic n-C_{17}.

Surface samples were collected at eight locations on December 3, 1976: 10 km NW (XLV), 10 km SE (XLVII), 10 km NE (XLIX), 10 km SW (LI), 2 km NW (LIII), 2 km SE (LV), 2 km NE (LVII), and 2 km SW (LVIII) of the center of the oilfield. The greatest concentration was found in the sample collected 2 km SW of the center of the oilfield (LVIII, 11.8 ppb), but there was no clear evidence that these hydrocarbons were petroleum derived. Two of the remaining samples did not contain alkanes (LI, LIII) while the others contained less than 5 ppb of hydrocarbons.

Two weeks later, on December 17, 1976, surface water samples were collected various distances from the center of the oilfield: 1.6 km N (LX), 1.2 km N (LXI), the center (LXII), 1.2 km S (LXIII), 1.6 km S (LXIV), and 1.6 km E (LXVIII). (Platform A is 1.4 km N and platform B is 1.4 km S of the center of the oilfield.) The alkane concentrations in the samples were within a fairly narrow range (1-5 ppb), and there was no discernible concentration gradient. In each of the nine samples, the C_{14} to C_{21} alkanes exhibited a petroleum-like distribution.

Surface samples were collected at three locations February 15-17, 1977: 10 km SW (LXIX), at the center of the oilfield (LXXI), and 10 km NE (LXXIII). The principal alkane in these samples, n-C_{17}, was a compound of biogenic origin.

Two additional samples were collected on March 2, 1977. A sample from the vicinity of a well jacket (LXXV) and another adjacent to platform B (LXXVI) each contained less than 0.4 ppb of alkanes, with no indication of petroleum contamination.

Bottom Water Samples

A bottom water sample (III) collected below the brine discharge pipe at platform A contained 5.3 ppb of alkanes. The n-heptadecane/pristane ratio (1.2) and the n-octadecane/phytane ratio (3.03) are similar to those obtained from discharged brine samples. There is a bimodal distribution of alkanes with the maximum for the petroleum distribution at C_{16}, while the major maximum was at C_{32}. It is probable that the alkanes from C_{26} to C_{37} are bacterial in origin (Davis, 1968; Albro, 1976).

Bottom samples collected at random locations (V-VIII, IX, XII) during June and July, 1976 also contained bacterial hydrocarbons. With the exception of sample IX, the branched alkanes pristane and phytane were absent from bottom samples. It is of interest to note that where both surface and bottom samples were analyzed (VII,IX; XI,XII) alkane concentrations were greater in the former.

Samples collected during August 31 and September 1, 1976 along a transect running from a point 10 km SW of the center of the oilfield to a point 10 km NE also exhibited a bimodal alkane distribution with it most apparent in the SW (Fig. 10). Alkane concentrations in the SW ranged from 23.4 (XIV) to 7.9 (XVI) ppb, with the maximum concentration at the end of the transect. To the NE, alkane concentrations were found only in the range 1.4 (XXIV) to 5.3 (XVIII) ppb. A prevailing bottom current flows through the region of the oilfield from NE to SW, so the greater concentration of hydrocarbons is downstream. The major components, around C_{33}, are apparently of bacterial origin, whereas those around C_{20}, exhibit a distribution characteristic of petroleum alkanes (Figs. 11, 12).

Samples collected at the same five locations on September 23, 1976 (XXXVI, XXXVIII, XL, XLII, XLIV) as the surface water samples contained less than 0.6 ppb of alkanes, with no indication of petroleum contamination or bacterial hydrocarbons. A similar sampling regime on December 3, 1976 yielded only two samples (XLVIII, L) with alkanes, but these appeared to derive neither from petroleum nor bacteria. Bottom samples collected at three locations on February 15-17, 1977 (LXX, LXXII, LXXIV) had one principal component, the biogenic hydrocarbon n-C_{17}.

Bottom water samples were collected in conjunction with sediment samples along a transect running 200 m east of platform A to 200 m west and a separate transect running 200 m east of well jacket B to 200 m west. Only one sample (LXXXVII), containing less than 2 ppb of hydrocarbons, exhibited a profile similar to that for "weathered" petroleum. However all samples containing more than 3 ppb of hydrocarbons showed petroleum profiles. For example, samples from three of the five locations in the vicinity of platform A (LXXVIII, LXXIX, LXXXVI) contained alkanes in the range C_{21} to C_{32} with maxima at C_{27}-C_{29}. The other two locations (LXXXIII, LXXXIX) afforded an alkane distribution from C_{17} increasing to a maximum at C_{19} and then decreasing to C_{30}, which is more characteristic of fresh oil. Six of the seven samples collected from locations adjacent to the well jacket had the same profile representative of fresh oil (XCI, XCII, XCV, XCIX, CI, CII). The other sample (C) could possibly contain "weathered" petroleum hydrocarbons at low concentrations (3 ppb).

Summary

Several conclusions can be made from the data presented:

1. Hydrocarbon distributions in the vicinity of the production platforms are influenced by wind direction rather than current direction.
2. Most surface water samples contained petroleum derived alkanes.
3. Concentrations and alkane content were similar to those reported by Iliffe and Calder (1974) for the eastern Gulf of Mexico and the Caribbean Sea, and those reported for other locations (Barbier *et al*., 1973; Brown and Huffman, 1976).
4. When both surface and bottom water samples were collected from the same location, alkane concentrations were greater in the former.
5. Hydrocarbon concentrations in bottom water samples are greatest downstream in the prevailing bottom current.
6. Many of the bottom water samples collected from locations more than 200 m from the production platforms have a bimodal hydrocarbon distribution. Alkanes around C_{20} exhibit a distribution characteristic of petroleum alkanes, while the major components, around C_{33}, are apparently of bacterial origin.
7. Bottom water samples collected within 200 m of the production platform contained only petroleum alkanes.
8. Half of the bottom water samples collected along transects through the production platform and through a well jacket contained petroleum alkanes.

It is clear that hydrocarbon distributions are very dependent upon wind and current direction. It also appears that the discharge of hydrocarbons from the production platforms has not significantly raised the hydrocarbon levels in the Gulf of Mexico.

SEDIMENTS

Of the 106 samples collected in the study area, the majority were collected within 200 m of the production platforms. This allowed for an intensive study of sediment alkane content in areas most likely to be influenced by the production activities. The other samples, 48 in total, provided a survey of sediment hydrocarbons necessary for complete characterization of the study area (Tables 22-24).

Hydrocarbon Distributions

Twenty-six surficial sediment samples were collected in the vicinity of the production platforms. One sample was obtained below the center of each platform and another (SW) below the brine discharge pipe. Location NE is below the northeast corner of the platform, and other NE locations are 8, 16.5, and, 25 m north of this point. Similarly, SE is below the southeast corner of the platform and SE 8, SE 16.5, and SE 25 are south of that point. A similar sampling pattern was employed for the NW locations.

Several features of the data are evident:

1. The highest concentrations of alkanes are found below the centers of the platform [14.3 ppm, Pfm B (LXII); 21.65 ppm, Pfm A (LXXVI)].

2. Concentrations of alkanes decreased with increasing distance from the platform (Fig. 13).

3. OEP values range from 0.57 to 1.07.

4. The alkanes appear to derive from Buccaneer crude oil. The n-heptadecane/pristane ratios range from 0.8 to 1.25, and the n-octadecane/phytane ratios from 1.0 to 3.13. The n-heptadecane/pristane ratio and the n-octadecane/phytane ratio for the discharged brine were, respectively, 1.05 and 2.44, similar to those seen in sediments.

5. The oil in the sediments is relatively fresh, with concentration maxima between n-C_{17} and n-C_{20}, comparable to those in discharged brine (Fig. 14). The weathering process, which involves evaporation, solution, oxidation, and metabolism, preferentially affects the lighter components of oil, so that concentration maxima shift to compounds of greater chain length as these processes proceed.

6. There are still significant amounts of oil (0.14-0.92 ppm) in sediments 25 m from the platforms.

Additional samples were collected from the vicinity of platform A in October, 1977 to determine whether fresh oil could still be observed in the sediments. Fifteen samples were collected along a transect extending from a point 183 m west of the platform to a point 183 m east of the platform. Samples were numbered in the same manner as the October, 1976 collections.

The concentration of alkanes below the platform was surprisingly low, only 0.19 ppm (LXXVII). The increase in alkane concentrations from C_{21} to a maximum at C_{26} with a decrease to C_{31} is indicative of weathered petroleum (Fig. 15). The OEP value was 0.95, also indicating a petroleum origin for the alkanes since recent marine sediments from the Gulf of Mexico have a marked odd-carbon preference with dominant hydrocarbons at n-C_{29} and n-C_{31} (Stevens et al., 1956; Evans et al., 1957).

The samples collected along the transect to the east of platform A (LXXVII-LXXXIV) all contained weathered petroleum alkanes. The highest concentration was 8 m from the platform (LXXVIII, 3.4 ppm). However, the other concentrations were all less than 0.37 ppm. Stations along the western transect had higher alkane concentration, which was expected since the prevailing bottom current in the area flows from NE to SW. Three samples, 8 m (LXXXV), 50 m (LXXXIX), and 200 m (XCI) from the platform had the appearance of relatively fresh hydrocarbons (concentration maxima at n-C_{20} or n-C_{15}) similar to profiles of sediments from locations where major oil spills have occurred (Ehrhardt and Blumer, 1972). Two stations, 16.5 m (LXXVI) and 100 m (XC), had concentration maxima at n-C_{24} or n-C_{25} with profiles similar to the sediments containing weathered petroleum alkanes along the eastern transect. The other two samples, 25 m (LXXXVII) and 33 m (LXXXVIII) did not contain petroleum alkanes.

The possibility was considered that the petroleum could have entered the sediments by seepage along the outside of well pipes. There are no discharges from well jacket structures, so sediments were collected along a transect running from a point 183 m west of well jacket B to a point 183 m east of the well jacket. There were no alkanes in the sample collected from below the structure (XCII). Only one sample (CV) contained alkanes in concentrations greater than 50 ppb. In addition to the concentration of alkanes (1.11 ppm), the sediment had a profile which increased from C_{20} to a maximum at C_{26} and then decreasing to C_{34}. This profile, combined with an OEP of 0.97, is indicative of weathered petroleum. There was no concentration gradient of alkanes along the transect and, due to the low concentration of alkanes, it could not be determined if the compounds were biogenic. It appears that petroleum alkanes in the Buccaneer field are not the result of oil seepage along the well pipes, but appear to be distributed by some other mechanism.

Water samples collected in conjunction with the sediment samples near the platform afforded slightly different analytical data. The water sample collected 8 m east of the platform (LXXVIII) had a weathered alkane profile as did the sediment sample from the same location. However, three other water samples (LXXIX, LXXXIII, XCI) contained petroleum alkanes while the corresponding sediments did not. A similar problem was encountered in the twin samples along the western transect. Two water samples with high levels of hydrocarbon pollution (LXXXVI, LXXXVII) corresponded to sediment samples which did not contain petroleum alkanes. One location (LXXXIX) had fresh petroleum alkanes in both sediment and water samples.

An even more interesting paradox was presented by the pairs of samples from the transects at the well jacket location. Water samples (XCII, XCV, XCIX-CII) all contained petroleum alkanes while the corresponding sediments did not; in fact, two sediments (XCII, XCV) did not have any alkanes.

The most plausible explanation for the disparity of analytical results is that the sediments in many areas are "scoured". In effect, currents remove the silt and sand from the sediment surface leaving the Beaumont clay formation exposed (Anderson, 1976; Martin, 1977). These fine particles remain in the water column; therefore, petroleum alkanes are seen in the water samples instead of the sediments.

In order to test this hypothesis, water samples (VII, VIII; Table 26) were collected and filtered, and the particulate matter analyzed. Due to a lack of sufficient material, hydrocarbons were not obtained in the analysis.

Benzo[a]pyrene was present in sediments along the well jacket transect in concentrations ranging from 0.15 to 0.75 ppb (average, 0.39 ppb). Sediments along the eastern transect of platform A contained an average benzo[a]pyrene content of 0.73 ppb (range 0.38 to 1.59 ppb). In contrast, the sediments down current from the platform had an average benzo[a]pyrene content of 78.13 ppb (range 0.31 to 487 ppb). The sediment with the highest benzo[a]pyrene content (LXXXVII) did not contain alkanes. In contrast, the sample with the lowest benzo[a]pyrene concentration (LXXXVIII) also did not have petroleum alkanes. The other sediments showed a correspondence between petroleum alkane profile and benzo[a]pyrene content. Due to the direction of the current, it was expected that carcinogens would be found in significantly higher concentrations on the western side of the production platform. However there appears to be a background level of benzo[a]pyrene throughout the oilfield.

Unlike the results of analyses for benzo[a]pyrene, the majority of samples which had measurable levels of methylnaphthalene contained petroleum alkanes as well (LXXVIII, LXXXV, XC, XCI, CV). In fact, the only sediment sample from the well jacket transect (CV) with methylnaphthalene present was also the sediment which contained petroleum hydrocarbons.

The discharged brine contains 0.006 to 0.11% elemental sulfur. If the discharged brine is the major source of petroleum contamination, then it would be expected that sulfur would be present in the sediments. Sulfur concentrations along the transect through the production platform ranged from 0.3 to 11.85 ppm; the range for the well jacket transect was 0.44 to 9.50 ppm. The average concentration of sulfur on the west side of the production platform (4.67 ppm) is twice as high as the concentration on the east side (2.30 ppm). The same trend is evident for the well jacket samples: 3.29 ppm for the east side and 5.02 ppm for the west side. These results, like the petroleum alkane and benzo[a]pyrene data correlate with current direction. It appears that sulfur is widely distributed throughout the oilfield area. This has important biological implications since sulfur is important in microbial metabolism (Meyer, 1977). Microorganisms are a basic component of the food web; therefore the availability of these bacteria encourages the growth of other marine organisms.

A total of 44 sediment samples were collected from locations more distant (0.7 to 11 km) from the production platforms. (Fig. 16). The alkane content in these samples ranged from 30 ppb (XV) to 3.0 ppm (VII).

Most of these samples can be characterized as containing alkanes of a recent biogenic origin. Notable in this category are the odd-chain C_{15} to C_{21} alkanes, formed presumably by decarboxylation of C_{16} to C_{22} even-chain fatty acids (Albro, 1976). The prominent odd-chain C_{25} to C_{35} n-alkanes in sample X are characteristic of higher plants (Han and Calvin, 1969), and have frequently been reported in sediments from the Gulf of Mexico (Stevens et al., 1956; Gearing et al., 1977) and elsewhere (Bray and Evans, 1961; Gaskell et al., 1975) (Fig. 17). The only alkanes which are likely to be of petroleum origin are those which occur with a range of chain lengths exhibiting a low OEP value. Sample VII could be considered in this cateogry, since the C_{22} to C_{35} alkanes have an OEP value of 1.15. Such petroleum-like profiles are also found in XXX (OEP, 1.18; 593 ppb), XXIV (OEP 1.18; 118 ppb) and XXI (OEP, 1.42; 136 ppb) and, less distinctly, in samples X, XII, XXV, XXVII, XLI, XLII, III, and V. A petroleum profile in the n-C_{15} to n-C_{19} range can be seen in XXXIII (OEP, 1.08; 980 ppb).

While the hydrocarbons in these samples are most likely petroleum derived, other possibilities must be considered. A low OEP value has been found for bacterial alkanes (Han and Calvin, 1969; Davis, 1968; Johnson and Calder, 1973), as well as some corals and sponges (Koons *et al*., 1965). Moreover, microbial action upon plant lipids has been shown to produce similar profiles (Johnson and Calder, 1973).

Summary

The effects of oil in the discharged brine appear to be limited to the appearance of petroleum alkanes in sediment samples collected within 200 m of the production platforms, since few of the samples collected at greater distances from the production platforms contained petroleum hydrocarbons. Sulfur and benzo[a]pyrene appear to be widely distributed throughout the area in the vicinity of the production platform. Unfortunately, similar data for samples collected at distances from the platforms are not available. This is necessary in order to determine if these compounds are even more widely distributed. Unlike the sulfur and benzo[a]pyrene data, there is good correlation between methynaphthalene and petroleum alkane concentrations. It would appear that these compounds are distributed by the same mechanism, while sulfur and benzo[a]pyrene appear to be distributed by a different mechanism.

There are several routes by which petroleum can be incorporated into fecal pellets of zooplankton, thus providing a mechanism for transport of hydrocarbons into sediments. This has been shown to be a distribution method for polychlorinated biphenyls (Elder and Fowler, 1977). Many of the biota in the oilfield feed on particulate matter. If particulates, such as sulfur, have hydrocarbons adsorbed, then ingestion of particulates by fish or hydroids could lead to incorporation of these compounds into fecal pellets.

BARNACLES

Seventy pairs (flesh and shell) of barnacle samples (Tables 7-9) were obtained from production platforms, flare stacks, quarters platforms, and well jackets. The wide distribution of samples allowed for comparison of data and statistical analysis of the hydrocarbon distributions. Within each set of samples (production platform, flare stack, *etc*.), barnacles were obtained at the surface and various depths below the surface, allowing for comparison of hydrocarbon concentrations between surface samples and subsurface samples. For analysis, flesh was separated from the shells, but no attempt was made to remove attached organisms such as vegetation, sponges, and corals from the shells.

Platform Samples

Twenty pairs (flesh and shell) of barnacle samples from the legs of the production platform were analyzed. Of the ten flesh samples obtained at depths of 10 m or greater, four (LXVI, LXX, CXVIII, CXXI) had maximum concentrations at $\underline{n}$-C_{25} or $\underline{n}$-C_{26}. The alkane profile from C_{22} to C_{32} for these samples indicated that these compounds were petroleum derived (Fig. 18). Two other samples (XXXIX, LVIII), with maximum concentrations at the biogenic hydrocarbons $\underline{n}$-C_{15} or $\underline{n}$-C_{21}, also had secondary maxima at $\underline{n}$-C_{27}, indicating that these samples contained a small amount of petroleum hydrocarbon. The other four samples (III, VII, XCIV, XCVIII) did not contain petroleum alkanes. Both samples screened for carcinogens contained benzo[a]pyrene (XCIV, 3.6 ppb; CXVIII, 18.6 ppb).

The dominant hydrocarbons in the majority of surface flesh samples were n-C$_{15}$, n-C$_{17}$, n-C$_{21}$, and pristane. Pristane usually comprised up to 50% of the total alkane content. In one sample (LVII), however, the pristane concentration was 2070 ppb, whie total n-alkane concentration was only 795 ppb. One sample (LXIV) appeared to be contaminated with alkanes which were only slightly weathered, while others had maxima at n-C$_{25}$ or n-C$_{26}$. The difference in the average concentration of the seven samples which contained petroleum alkanes (1648 ppb) was significantly greater ($p<0.025$) than the three which did not (392 ppb). Both samples containing benzo[a]pyrene (4.2 ppb, XCII; 20.3 ppb, CXVI) also contained petroleum alkanes.

It is interesting to note that concentration differences between polluted surface flesh samples and polluted submerged flesh samples are significant ($p<0.05$). Since surface water samples have been shown to contain petroleum alkanes, it was expected that flesh samples obtained from surface barnacle growth would also contain significantly higher concentrations of petroleum hydrocarbons. It should be noted that n-heptadecane/pristane values for contaminated samples varied from 0.01 to 0.24, while n-octadecane/ phytane values varied from 0.2 to 1.08. OEP values ranged from 1.0 to 5.29 for the same samples.

The corresponding shell (plus attached biota) were also analyzed. One sample (XCVII) did not contain petroleum alkanes. It appeared that two surface shell samples (CXVIII, LXV) contained fresh petroleum, since they had a decreasing alkane concentration from C$_{15}$ to C$_{32}$. Even though the other samples contained alkanes with increasing concentration from C$_{22}$ to C$_{25}$ and then decreasing to C$_{32}$, the biogenic hydrocarbons C$_{15}$, C$_{17}$, C$_{21}$, and pristane were still major alkanes. These same profiles were evident in only three subsurface shell samples (IV, VIII, XL). The other subsurface samples contained their major alkanes in the petroleum region from C$_{22}$ to C$_{32}$ (Fig. 19). n-Heptadecane/pristane ratios ranged from 0.25 to 2.17 for contaminated shell samples, while n-octadecane/phytane values ranged from 0.6 to 6 for the same samples. OEP values had only a four-fold range, 0.87 to 3.55. Both samples selected for carcinogen screening contained methylnaphthalene (4.0 ppb, CXVII; 1.3 ppb, CXIX).

Quarters Platform Samples

Three (LXXII, LXXVI, CXXIV) of the six flesh samples collected at the air-sea interface contained petroleum alkanes. Pristane, however, was the dominant hydrocarbon in two of the analyses (LXXII, LXXVI). In the three samples containing only biogenic hydrocarbons (C, CIV, CXXVIII), n-C$_{17}$ and pristane were the major alkanes. The difference in the average n-heptadecane/pristane ratio for contaminated and noncontaminated samples was not significant. All six shell samples (LXXIII, LXXVII, CI, CV, CXXV, CXXIX) contained petroleum pollution in the C$_{22}$ to C$_{34}$ region.

Four (LXXIV, LXXVIII, CXXVI, CXXX) of the six samples, obtained at a depth of 20 m, contained petroleum alkanes in the C$_{22}$ to C$_{32}$ region. Only one sample (LXXIV) had biogenic hydrocarbons such as n-C$_{17}$ and pristane. Its n-heptadecane/pristane ratio was 0.08 and the n-octadecane/phytane ratio wa

0.29, while the OEP was 1.16. These hydrocarbons, as well as n-C_{15} and n-C_{21}, were dominant in the samples which were not polluted (CII, CVI). The n-heptadecane/pristane ratios for these samples were 0.1, while the OEP values were 1.3 and 1.5, respectively. All six of the corresponding shell samples (LXXV, LXXIX, CIII, CVII, CXXVII, CXXXI) contained petroleum alkanes in the C_{22} to C_{34} region.

Flare Stack

The flare stack is operated as a safety valve to reduce pressure on the production platforms. Biota growing on this structure are subject only to periodic acute discharges of petroleum constituents. Barnacle flesh and shells, obtained at the air-sea interface and at a depth of 20 m, contained petroleum alkanes. In the surface flesh sample (LXXXVIII) pristane accounted for 76% of the total hydrocarbon content; while in the other flesh sample (XC) this isoprenoid comprised 51% of the total hydrocarbon content.

Well Jacket Samples

All of the remaining samples were obtained from well jackets at various locations throughout the study area. Four (LXXXII, LXXXVI, CXXXII, CXXXIX) of the twenty-two subsurface samples contained petroleum alkanes in the C_{22} to C_{32} region, but in only two (LXXXII, LXXXVI) did the petroleum alkanes dominate the biogenic alkanes. n-Heptadecane/pristane values for noncontaminated samples ranged from 0.01 to 2.6, while n-octadecane/phytane values ranged from 0.1 to 5.88. OEP values for the same flesh samples ranged from 2.45 to 48. The opposite data were obtained for subsurface shell samples. All but two (XLVIII, LII) contained petroleum alkanes. The major alkanes in these samples were C_{15}, C_{17}, and pristane, as well as for over half of the remaining contaminated samples. OEP values for contaminated subsurface shell samples ranged from 0.99 to 3.52; n-heptadecane/phytane values ranged from 0.6 to 7.6, and the n-octadecane/phytane ratios ranged from 1.0 to 12.0.

Similar to the subsurface flesh samples, only five surface flesh samples (XXV, LXXX, LXXXIV, CXXXII, CXXXVII) contained petroleum alkanes. The contaminated sample selected for carcinogen screening (CXXXII) contained 4.2 ppb of methylnaphthalenes. The major alkanes in the non-polluted samples were C_{15}, C_{17}, C_{21}, and pristane. Pristane usually accounted for more than 50% of the total alkane content. Unlike flesh samples, all but one (XLII) of the surface shell samples contained petroleum alkanes. One contaminated sample did not contain carcinogens while the other had 2.2 ppb of benzo[a]pyrene. Despite the presence of petroleum alkanes, the biogenic hydrocarbons were still major components of the total alkane content.

Summary

Only four shell samples did not contain petroleum alkanes. The difference in concentration between surface shells from the production platform (1792 ppb) and surface shells from the well jackets (449 ppb) was significant ($p<0.0375$). Hydroids and corals which reside on barnacle shells have biogenic alkane profiles which resemble a petroleum alkane profile. It is possible that hydrocarbons on well jacket shells are due to the attached biota, and therefore, represent a "natural" background level of hydrocarbons. Levels significantly higher, such as from shells on the production platform, would represent the hydrocarbon burden imposed by oil production activities. This is further supported by the fact that only eight flesh samples from the well jackets contained petroleum alkanes, while all but seven flesh samples from the production platform contained petroleum alkanes.

Even in platform samples, the biogenic alkanes C_{15}, C_{17}, C_{21}, and pristane were often the dominant hydrocarbons. This was more evident in samples from the quarters platform and the well jacket samples. In most cases, the petroleum alkanes contributed by the discharged brine are in minor concentrations compared to the biogenic hydrocarbons.

The major environmental indicators for petroleum pollution, n-heptadecane/pristane, n-octadecane/phytane, and OEP ratios, varied widely in contaminated samples. This was often due to the fact that biogenic alkanes were the dominant hydrocarbons, therefore this reduces the utility of these indicators for biological samples.

BENTHIC ORGANISMS

Like barnacles, most benthic organisms are sedentary. Examination of species representative of the ecology of the study area provided a more complete picture of the effects of oil production. Forty-eight samples from the classes of Bivalvia, Gastropoda, Hydrozoa, and Anthozoa were collected from the production platform, quarters platform, and well jackets were analyzed. (Table 19-21)

Alcyonaria (yellow coral)

Alcyonaria samples (IV, XIX, XXXIV) obtained at the platform-sediment interface had similar alkane distribution profiles. There was an increase in the alkane content from C_{22} up to a maximum at C_{26}, and then a decreasing alkane content to C_{32}. The n-heptadecane/pristane ratio in the two samples containing pristane was low, 0.21 (IV) and 0.2 (XXXIV) indicating that these hydrocarbons are biogenic. The OEP values ranged from 1.0 to 1.17 for the three samples.

Only one sample was collected from the quarters platform (XXIII), and it did not contain hydrocarbons.

The same profile was evident in samples obtained at the well jacket site as in the samples obtained at the production platform. Two of the samples (X,XLVII) had a maximum hydrocarbon concentration at n-C_{25}, while the third (XXVI) contained a maximum at n-C_{28}. The OEP values for all three samples ranged from 0.99 to 1.15, and the samples containing pristane showed low n-heptadecane/pristane ratios, 0.14 (X) and 0.2 (XXVI).

Koons et al. (1965) reported that Coelenterata (horny coral) showed low OEP values (1.1), as compared with distribution in land plants. The results of our analyses from samples obtained from the production platform and well jacket are similar. Due to the homogeneity of alkane profiles from all the samples, it can be concluded that these samples are not polluted with alkanes, and that the hydrocarbons in the samples are biogenic.

It is possible that some of the samples have been contaminated by the aromatic compounds in the brine. For example, samples (XIX, XXXIV) from the

0.29, while the OEP was 1.16. These hydrocarbons, as well as n-C_{15} and n-C_{21}, were dominant in the samples which were not polluted (CII, CVI). The n-heptadecane/pristane ratios for these samples were 0.1, while the OEP values were 1.3 and 1.5, respectively. All six of the corresponding shell samples (LXXV, LXXIX, CIII, CVII, CXXVII, CXXXI) contained petroleum alkanes in the C_{22} to C_{34} region.

Flare Stack

The flare stack is operated as a safety valve to reduce pressure on the production platforms. Biota growing on this structure are subject only to periodic acute discharges of petroleum constituents. Barnacle flesh and shells, obtained at the air-sea interface and at a depth of 20 m, contained petroleum alkanes. In the surface flesh sample (LXXXVIII) pristane accounted for 76% of the total hydrocarbon content; while in the other flesh sample (XC) this isoprenoid comprised 51% of the total hydrocarbon content.

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It is possible that some of the samples have been contaminated by the aromatic compounds in the brine. For example, samples (XIX, XXXIV) from the production platform contained benzo[a]pyrene. One of the samples (XXXIV), and two from the well jacket location (XXVI, XLVII) contained methylnaphthalenes. Since benzo[a]pyrene is not water-soluble, it may be adsorbed onto particulates (such as sulfur) ingested by the corals. However, the methylnaphthalene compounds, which have a greater solubility, are present in samples from the well jacket location. These organisms are not mobile, so these compounds may be concentrated from the surrounding water.

Hydroida (brown hydroid)

Five samples obtained from the production platform-sediment interface were analyzed. Four of the specimens (V, XXI, XXXI, XXXII) had an increasing hydrocarbon content from $\underline{n}$-C_{22} to a maximum at $\underline{n}$-C_{27} or $\underline{n}$-C_{28}, and then decreasing alkane content to $\underline{n}$-C_{32} or $\underline{n}$-C_{34} (Fig. 20). The fifth sample (VIII) only contained alkanes from C_{26} to C_{31}. The OEP values ranged from 0.83 to 1.47, and the concentrations ranged from 940 ppb to 34.8 ppm. If pristane was present in the samples, the $\underline{n}$-heptadecane/pristane values were low, 0.07 (V) and 0.29(XXI).

Three representatives of Hydroida were collected from the quarters platform. The hydrocarbon profiles were the same as the profiles of samples from the production platform, with maxima at $\underline{n}$-C_{26} (XL), $\underline{n}$-C_{27} (XXXIX), and $\underline{n}$-C_{28} (XXIV). OEP values were similar, 0.83 to 1.10, as were concentration ranges, 3.4 ppm to 10.3 ppm. Pristane was not present in any samples.

One brown hydroid from the well jacket location was analyzed (XXVII). The hydrocarbon profile was similar to profiles from the previous specimens: OEP, 1.15; maximum, $\underline{n}$-C_{27}; $\underline{n}$-heptadecane/pristane ratio, 0.17.

Three of the hydroid specimens from the production platform contained benzo[a]pyrene (XXI, XXXI, XXXII), while one (XXXII) also contained methylnaphthalene. None of samples from the quarters platform or the well jacket location contained these compounds.

Hydroida are filter-feeders, and it is possible that the alkane profiles and carcinogen content result from the ingestion of particulates coated with weathered oil. However only one sample from the production platform (V) had a greater total hydrocarbon content (34.5 ppm) than the sample from well jacket location (12.9 ppm). It is possible that the hydrocarbon content reflects the biogenic alkane profile of this class of marine organisms; however, more samples from the well jacket location need to be analyzed in order to verify this conclusion.

Pteria colymbus (winged oyster)

Of the six specimens obtained from the production platform, only two contained alkanes (XVI, XXXV). The total alkane concentration for XVI and XXXV were 150 ppb and 420 ppb, respectively, and the OEP values were 1.31 and 1.8, respectively. The alkane profile in XVI decreased from C_{26} to C_{31}, while the alkanes in the C_{23}-C_{30} region of the chromatogram of XXXV had a marked even-carbon preference.

Three samples from the vicinity of the well jacket location were analyzed. One did not contain hydrocarbons (IX), while the other two contained 2.7 ppm of $\underline{n}$-alkanes. The OEP value for XLIV was 8.31 due to $\underline{n}$-C_{21}

constituting 66% of the sample, however both samples also had large amounts of n-C_{31}. Both specimens had an increasing alkane content from C_{22} up to C_{25} (XLIV) or C_{27}(XLV).

Five of the six specimens from the production platform (XVI, XX, XXII, XXXV, XXXVI) contained methylnaphthalene or benzo[a]pyrene in their tissues. None of the samples from the well jacket location or the quarters platform contained these compounds. Therefore, it is obvious that these are concentrated from the surrounding water or are adsorbed onto particulate matter on which these molluscs feed and are due to oil production.

Pleuroploea gigantea (Florida horse conch)

The total alkane content of the five specimens obtained in the vicinity of the production platform varied from 0 ppb (XVII) to 2.3 ppm (XVIII). The OEP values ranged from 0.70 (XVIII) to 1.1 (VII). The alkane profiles were nondescript. For example, VII contained alkanes in the region C_{23}-C_{27}, while XXIX contained alkanes in the chromatogram area of C_{26}-C_{30}.

Samples in the vicinity of the quarters platform contained 0 ppb (XXV), 215 ppb (XXXVII), and 4.64 ppm (XXXVIII) of total alkanes. The OEP values for XXXVII and XXXVIII were 1.04 and 1.05, respectively, and the alkane profiles were as seen in other samples.

Of the three specimens from the vicinity of the well jacket, two did not contain alkanes (XLII, XXVIII). The major alkanes in XLIII were C_{17} (61%) and C_{21} (20%), which are both biogenic.

A sample from the vicinity of the flare stack (XII) did not contain alkanes.

Due to the difference in hydrocarbon content between the well jacket samples and the specimens from the vicinity of the production and quarters platforms, it can be concluded that if the latter samples contain alkanes, then they are contaminated with petroleum.

This conclusion is supported by additional evidence from the carcinogen screening. Three of the four samples from the production platform (XVIII, XXIX, XXX) contained benzo[a]pyrene and alkanes as did the two samples from the quarters platform (XXXVII, XXXVIII). One of the samples from the well jacket which did not contain alkanes, however, had 3.0 ppb of methylnaphthalene. These molluscs are very mobile (Gallaway, 1987) so it is possible that this specimen had previously been located near the production platform.

Arbacia unctulata (sea urchin)

The OEP value for the sample (XXXIII) collected near the production platform was 0.1 resulting from the dominance of n-C_{18} and n-C_{22} hydrocarbons. This sample also contained 1.2 ppb of total methylnaphthalenes. Specimens obtained from the vicinity of the well jackets gave disparate analytical results. One sample (III) did not contain alkanes, while another (II) had 66% of its alkane content in the C_{19} and C_{21} peaks. In the third sample (XLVI) n-C_{21} and n-C_{28} were the dominant hydrocarbons, as was benzo[a]pyrene (19 ppb).

Murex fulvescens (giant eastern murex)

None of these samples (XI, XIII, XLI, XLVIII) contained alkanes. However, XLVIII, contained 34.0 and 15.0 ppb of benzo[a]pyrene and methylnaphthalene, respectively.

Pagurus floridanus (hermit crab)

This specimen (XIV) did not contain alkanes.

Fasciolaria hunteria (banded tulip shell)

This sample (XV) did not contain alkanes.

Chloeia viridus (brittle-worm)

This sample (I) contained as its dominant hydrocarbons $\underline{n}$-C_{20}, $\underline{n}$-C_{21}, and $\underline{n}$-C_{22}.

Summary

All but one of the Alcyonaria samples contained alkanes in the C_{22} to C_{32} region. While this has been used as an indicator for pollution in other samples, there is evidence that these compounds are biogenic (Koons *et al.*, 1965). Representatives from the class Hydroida had similar profiles, but only one sample from the well jacket location was analyzed so it was not possible to determine if the hydrocarbons in the production platform samples were the result of oil production activities. Few of the specimens of *Pteria colymbus* collected at the production platform contained petroleum alkanes, while they did contain methylnaphthalene or benzo[a]pyrene. Other species of molluscs (*Mytilus edulis*) have been postulated to metabolize aliphatic and olefinic hydrocarbons but not aromatics (Ehrhardt and Heinemann, 1975). This could also be possible for this species of mollusc. Specimens of a more mobile species of mollusc, *Pleuroploea gigantea*, had various hydrocarbon profiles which could be ascribed to petroleum contamination. The number of specimens of other species was not large enough to allow for any conclusions.

PLANKTON

Any concentrations of petroleum hydrocarbons in this basic component of the food web could lead to their ingestion by other biota. Due to the mobility of plankton, if there were large amounts of petroleum, this could enlarge the area in which the effects of the oilfield production activities are exerted. Forty-two plankton samples, obtained from various sectors of the study area, were analyzed (Tables 13-15).

Surface

Concentration of alkanes (ppb, wet weight) in surface samples are given in Table 14. The total $\underline{n}$-alkane concentrations ranged from 0 ppb (XXXVIII) to 52.4 ppm (XXXVI). Samples collected from the vicinity of the production platforms (XX, XXII, XXVIII, XXX, XXXVI) had similar alkane profiles. They increased from a minimum concentration at C_{22} up to a maximum concentration at C_{27} and then to a minimum at C_{34}. One sample (XXXVIII) did not contain hydrocarbons. For one sample, the high OEP (2.2), the low *n*-heptadecane/pristane ratio (0.55), and the dominance of the alkane *n*-C_{15} indicate that this sample is composed primarily of biogenic hydrocarbons. A second sample (XXVIII) had a low OEP. The *n*-heptadecane/pristane ratio (2.86), however, was higher than the values for Buccaneer discharged brine (mean, 1.05). It appears that this sample contains a general background of alkane contamination which could be due to Buccaneer discharged brine, but evidence is not conclusive. The two samples collected during the summer (XX, XXII) and one collected during the winter (XXXVI) had low OEP values (1.0-1.5) and *n*-heptadecane/pristane ratios similar to the ones for the discharged brine (0.85-1.49).

Other samples (XXIV, XXVI, XXXII, XXXIV, XL, XLII) were obtained from areas adjacent to well jackets. The alkane concentrations ranged from 1.3 ppm (XL) to 22.58 ppm (XXIV). One sample collected during the winter (XL) was dominated by *n*-C_{17}, n-C_{21}, and pristane (24.4%), indicating that these plankton are not contaminated with petroleum hydrocarbons. However, the other plankton samples could be slightly contaminated with petroleum since they exhibit the typical profile where the alkane concentration increases from C_{22} up to maxima at C_{27}-C_{29} and then to another minimum near C_{34}. One of the summer samples (XXIV) appeared to have been recently contaminated since the maximum concentration was at *n*-C_{15} and *n*-C_{16}.

Four samples (IX-XII) were collected along a transect running from a point 14 km NW of the oilfield to a point 10 km W of the oilfield. It is possible that the C_{20} to C_{35} alkanes in samples IX, XI, and XII were from petroleum. The alkanes in sample X were dominated by *n*-C_{15}, *n*-C_{19}, *n*-C_{31}, and *n*-C_{33}: the high OEP (11.05) is characteristic of biogenic hydrocarbons. Samples XIII, XIV, XV, and XVI were collected, respectively, from the NW, SE, NE, and SW quadrants of the oilfield. It is almost certain that the C_{18} to C_{37} *n*-alkanes from sample XIV are petroleum derived, and a similar distribution is observed, to a lesser extent, in samples XIII, XV, and XVI.

Subsurface

Three of the six subsurface samples collected near the production platforms did not contain alkanes (XXVII, XXXV, XXXVII). The two samples collected during the summer (XIX, XXI) were dominated by *n*-C_{15} and pristane, both of biogenic origin. A sample collected during the fall (XXIX) was contaminated with petroleum alkanes in the C_{20} to C_{36} range.

The majority of the subsurface plankton samples obtained in the region of the satellite well jackets were dominated by the biogenic hydrocarbons *n*-C_{15}, *n*-C_{17}, *n*-C_{21}, and pristane (XXV, XXXI, XXXIII). One of these had possible petroleum contamination in the *n*-C_{21} to *n*-C_{32} region (XXV), as did another sample in which these were the only alkanes present (XLI). One sample (XXIII), collected on July 14, 1977, was contaminated with fresh petroleum since there was a maximum alkane concentration at C_{17}.

Other plankton samples were collected in various quadrants of the oilfield. The first two samples collected on May 24, 1976 (I, II) were from the NW and SE quadrants, respectively of the field. Their alkane contents were almost identical, with C_{15} and C_{22} predominating. Sample III was collected on the same day from a location 10 km SE of the oilfield. It contained large amounts of C_{15} and C_{17}, but no petroleum alkanes. A sample collected from the NE quadrant of the oilfield (IV) contained very little *n*-C_{15}, and there was no clear evidence for petroleum contamination.

Four samples were collected during mid-August: from the NW quadrant (VI) and the NE quadrant (VII) of the oilfield and from points 10 km NW (V) and SE (VIII) of the center of the field. It is possible that the C_{19} to C_{24} alkanes in V are petroleum derived; however, the predominant hydrocarbons are *n*-C_{17} and pristane. Samples VI and VIII are similar in composition, and the C_{20} to C_{27} alkanes may tentatively be ascribed to petroleum contamination. Sample VIII was probably uncontaminated since the predominant hydrocarbons were *n*-C_{15}, *n*-C_{17}, and pristane.

Summary

The majority of surface plankton samples were contamined with petroleum alkanes. In two samples (XII, XXIV), tar balls were readily visible; these have been reported present during microscopic examination of other samples from these location (Finucane, 1977). The majority of subsurface samples contained only biogenic hydrocarbons, *n*-C_{15}, *n*-C_{17}, and pristane. It is possible that the petroleum hydrocarbons observed in surface samples were not contained within the plankton (inside the cells), but were due to the presence of minute particles of tar. This is still important since biota feeding on plankton would just as likely ingest tar balls as plankton.

SHRIMP AND SQUID

Due to the commerical importance of shrimp trawling in this region of the Gulf of Mexico, it was necessary to analyze various species of shrimp for their hydrocarbon content. Shrimp boats are often visible in the platform area and if hydrocarbon pollution were widespread, the ingestion of contaminated shrimp could provide a potential human health hazard. Twenty-four samples, representing five species of shrimp and one species of squid, were analyzed (Tables 10-12).

Analytical Data

Six shrimp samples were obtained by trawling between the production platforms on October 18, 1977. Four of these samples (XI, XII, XV, XVI) appear to be contaminated with petroleum alkanes in the C_{23} to C_{31} region (Fig. 21). The other *Penaeus aztecus* (XIII, XIV), however, have a marked predominance of odd-carbon number alkanes, C_{27}, C_{29}, and C_{31}. It is likely that these samples were not tainted by petroleum hydrocarbons (Fig. 22).

Five shrimp samples were obtained by trawling near the production platforms on August 10, 1976 and February 16, 1977. Two of the samples (III, IV), both *Penaeus aztecus*, were contaminated with petroleum hydrocarbons in the *n*-C_{20} to *n*-C_{30} region. The other shrimp, *Penaeus duorarum* (V), *Trachypenaeus similis* (VI), and *Squilla empusa* (VII), did not contain petroleum hydrocarbons.

Trachypenaeus similis obtained near platform B on March 10, 1978 (XVIII) did not contain petroleum alkanes. *Penaeus aztecus* (XVII) from the same location and *Trachypenaeus similis* (XXII) did not contain any hydrocarbons. The other shrimp (XIX-XXI, XXIII, XXIV) obtained from the platform region, however, contained petroleum alkanes in the C_{22} to C_{32} region. The OEP values for these samples ranged from 0.91 (XXIV) to 1.43 (XIX), also indicative of petroleum hydrocarbons.

Shrimp caught 10 km NE of the center of the oilfield on August 9, 1976 did not contain petroleum hydrocarbons (I).

Four squid samples (II, VIII, IX, X) were analyzed for their hydrocarbon content. The predominant hydrocarbons were $\underline{n}$-C_{15} and $\underline{n}$-C_{17}. This, in addition to the high OEP values (II, 24.6; VIII, 37.5; IX, 4.67; X, 25.3), indicated that these organisms contained only biogenic hydrocarbons.

Two of the shrimp samples (XI, XII) which had petroleum hydrocarbons contained 13.9 and 14.4 ppb of methylnaphthalenes, respectively (Table 39). *Trachypenaeus similis* which did not have petroleum alkanes, in contrast, had 1.3 ppb of methylnaphthalenes.

Summary

It appears that shrimp, an important commercial marine organism, are usually not contaminated with petroleum. Only one sample contained more than 3 ppm of hydrocarbons (XXI, 7.4 ppm), and none contained benzo[a]pyrene, a potent carcinogen. The majority of shrimp which had petroleum hydrocarbons were caught in areas adjacent to the production platforms.

FISH

The majority of analyses were centered upon specimens which permanently reside in the vicinity of platforms within the oilfield. The blennies (*Hypleurochilus geminatus* and *Blennius marmoreus*) reside in vacant barnacle shells, and it would be expected that their hydrocarbon concentrations would resemble those of barnacles. Red snapper (*Lutjanus campechanus*) are commercially significant. The other two major species, *Archosargus probatocephalus* (sheepshead) and *Chaetodipterus faber* (Atlantic spadefish), are habitat sessile so that migration would not complicate the data interpretation (Tables 16-18).

Hypeurochilus geminatus (crested blenny) and *Blennius marmoreus (seaweed blenny)*

These fish which inhabit empty barnacle shells, were collected from below the production platforms. Two samples (XCV, CXX) contained petroleum alkanes in the C_{22} to C_{32} region in concentrations of 3.63 ppm and 1.29 ppm, respectively. The third sample (CXXI) appeared to have fresh petroleum alkanes in the C_{15} to C_{20} region. It, however, also contained biogenic hydrocarbons at $\underline{n}$-C_{21}, $\underline{n}$-C_{25}, $\underline{n}$-C_{27}, and $\underline{n}$-C_{29} for a total alkane concentration of 12.15 ppm. The first two samples also contained benzo[a]-pyrene and methylnaphthalenes in their tissues, while the third did not have these compounds (Table 40).

Three additional samples (CII, CXXVI, CXXVII) obtained from the quarters platform all contained petroleum hydrocarbons in the C_{22} to C_{30} region, with an average concentration of 1.67 ppm. Sample CII did not contain methylnaphthalenes or benzo[a]-pyrene in its tissues, while CXXVII had both compounds (895 ppb and 5.6 ppb, respectively), and CXXVI included only methylnaphthalenes (5.2 ppb).

Additional samples obtained from the well jacket (CIX, CXXXIV, CXXXV) contained an average concentration of 0.53 ppm of alkanes. One of the specimens (CXXXIV) was composed of petroleum alkanes (0.30 ppm) in the C_{22} to C_{32} region, as well as 4.0 ppb of methylnaphthalenes. Another sample (CXXXV), which had a slight odd-carbon preference in this region, contained 12.7 ppb of methylnaphthalenes. It could not be determined if the hydrocarbons in CIX, which contained 3.0 ppb of methylnaphthalenes, were petroleum derived.

The difference in concentration for production platform and well jacket samples (5.69 ppm and 0.53 ppm, respectively) is significant ($p<0.001$). It would appear that these fish contain a biogenic hydrocarbon level which, in the presence of petroleum, can be elevated. Since these organisms reside in empty barnacle shells and feed on the algal mat encrusting the shells (Gallaway, 1978), it can be expected that the fish would contain hydrocarbons similar to those of barnacles.

Archosargus probatocephalus (sheepshead)

Two specimens were obtained from the production platforms, and both the livers and muscle were analyzed. One liver (CI) did not contain hydrocarbons, while the other (CXIX) contained 2.69 ppm of alkanes, predominantly C_{15} and C_{17}. Only the latter sample contained 93 ppb of benzo[a]pyrene. The muscle of one fish (C) was composed predominantly of n-C_{17} and n-C_{27}. This specimen had 15 ppb of benzo[a]pyrene. The other muscle (CXVIII), which contained 40.6 ppb of methylnaphthalenes, had petroleum hydrocarbons in the C_{21} to C_{31} region.

Of the two fish trapped near the quarters platform, it could not be determined if the muscles (CVII, CXXIV) contained petroleum hydrocarbons. They both contained methynaphthalenes. The major hydrocarbons of CXXIV were n-C_{17} and n-C_{23}. These data combined with an OEP value of 4.75, support the conclusion that these hydrocarbons are biogenic. The liver of this fish (CXXV) also had a slight odd-carbon preference (2.26), and the dominant hydrocarbons were n-C_{17} and n-C_{23}. It did, however, contain 53 ppb of benzo[a]pyrene. The other liver (CVIII) did not contain hydrocarbons.

Five specimens trapped in the vicinity of the well jackets were analyzed. Petroleum hydrocarbons in the n-C_{21} to n-C_{30} region were found in the muscle of three (LX, LXII, CXXXII), but not in the other two (LXIV, CXII). The muscle of CXXXII contained 12.8 ppb of methylnaphthalenes. Petroleum alkanes were present in the liver of only one specimen (LXV).

The difference in hydrocarbon levels of the fish from the well jackets and the fish caught near the production or quarters platform are similar. Since these fish are habitat sessile (Gallaway, 1978), the specimens probably would not have migrated from one structure to another. It is possible that significant differences would have been found if more specimens from the production platform had been analyzed.

Chaetodipterus faber (Atlantic spadefish)

Muscle and liver from six specimens obtained near the production platform were analyzed. Five of the muscle samples (LXX, LXXII, LXXIV, XCVIII, CXVI) contained petroleum hydrocarbons in the $\underline{n}$-C_{21} to $\underline{n}$-C_{32} region. In these samples, however, pristane was the dominant hydrocarbon (up to 50% of the total hydrocarbon content). The muscle of LVI was dominated by the biogenic hydrocarbons $\underline{n}$-C_{15} and $\underline{n}$-C_{18}. Three (LVII, XCIX, CXVII) of the livers contained petroleum alkanes. Two of the other livers (LXXI, LXXV) did not contain hydrocarbons, while it could not be ascertained if the hydrocarbons in LXXIII were petroleum derived. Both XCIX and CXVII contained benzo[a]pyrene (125 ppb and 49 ppb), while only CXVII contained methylnaphthalenes (33.6 ppb).

Two specimens collected near the quarters platform were analyzed. While neither of the livers (CVI, CXXIII) contained petroleum alkanes, CXXIII contained 6.7 ppb of methylnaphthalenes. The alkanes in muscle CXXII consisted of C_{15}, C_{17} and possible petroleum alkanes in the C_{20} to C_{30} region. While muscle CV contained 0.6 ppb of methylnaphthalenes, the alkanes were not petroleum derived.

The specimen trapped near the well jacket on October 28, 1977 (CX, CXI) did not contain alkanes, but the liver and muscle had 0.5 ppb and 4.0 ppb, respectively, of methynaphthalenes. The muscle of the other two samples (LXXIII, CXXX) contained petroleum alkanes. While one liver (CXXXI) also had petroleum alkanes (C_{21} to C_{30}), the other liver (LXXIV) did not appear to be contaminated.

While most of the muscle samples examined contained petroleum alkanes (73%), the samples were dominated by their pristane content. For example, the $\underline{n}$-heptadecane/pristane ratio of LXXII and LXXIV was 0.04. Since most of the pollution was in muscle samples, the hydrocarbons are probably adsorbed onto the skin from the surrounding water.

Lutjanus campechanus (red snapper)

Of the three specimens collected from the production platform, the livers of two (LXXXII, XCVII) contained petroleum alkanes. Sample XCVII also contained 40 and 4.5 ppb of benzo[a]pyrene and methylnaphthalenes, respectively. The third liver (CXV), composed primarily of the hydrocarbons $\underline{n}$-C_{15}, $\underline{n}$-C_{17}, and pristane, contained 61 ppb of benzo[a]pyrene. Two muscle samples (XCVI, CXIV) were examined; both contained petroleum alkanes. One muscle sample (XCVI) contained 6 ppb of benzo[a]pyrene, while the other (CXIV) had 5.4 ppb of methylnaphthalenes.

The muscle (CIII) and liver (CIV) of a sample trapped near the quarters platform contained 0.52 and 13.8 ppm, respectively, of alkanes. None appeared to be petroleum derived.

Four red snapper specimens were obtained from the vicinity of the well jacket site. The hydrocarbon content of the muscles and livers were dominated by the alkanes C_{15} and C_{17} and the isoprenoid, pristane. Three livers also contained petroleum alkanes (LXXXVII, LXXXIX, CXXIX), while only one (CXXIX) contained methylnaphthalenes. The corresponding muscle samples (LXXXVI, LXXXVIII, CXXVIII) also contained petroleum alkanes, while one muscle sample (CXXVIII) contained methylnaphthalenes.

Red snapper tend to move through the oilfield at night, but they remain near the platforms during the day (Gallaway, 1978). It is possible that the low level of hydrocarbon pollution, which was usually less than 50% of the total hydrocarbon content, was obtained near the production platforms. In addition, these fish feed on smaller fish and macrobenthos (Gallaway, 1978) so that ingestion of contaminated specimens could also lead to the low level of hydrocarbon pollution in livers.

Arius felis (sea catfish)

Two specimens were examined. Muscle samples contained 295 (XXVII) and 367 (XXXIII) ppb of alkanes. The major alkanes were C_{17} and pristane, and there were no petroleum alkanes. The livers contained 3.2 (XXVIII) and 0.78 (XXXIV) ppb of alkanes. *n*-Heneicosane predominated. It is possible that the C_{23} to C_{30} alkanes (0.38 ppm) in sample XXXIV were petroleum derived.

Balistes capriscus (gray triggerfish)

Two specimens were examined. The muscle (LXXX) and liver (LXXXI) of a sample trapped near the production platform contained petroleum alkanes; however the major hydrocarbons in the liver were *n*-C_{17}, *n*-C_{18}, and pristane. The other specimen, caught near the control well jacket, had a similar alkane distribution in the muscle (XC), but the liver (XCI) did not contain hydrocarbons.

Centropristis philadelphica (rock sea bass)

Muscle tissue (XXXIX) contained only *n*-C_{16} (25 ppb) and *n*-C_{17} (150 ppb), while no alkanes were detected in the liver (XL).

Citharichthys spilopterus (bay whiff)

The muscle sample (L) analyzed contained only 51 ppb, but the C_{22} to C_{31} alkanes exhibited the characteristic petroleum distribution. The liver was not examined.

Cynoscion arenarius (sand seatrout)

Three specimens were analyzed. There was little pristane in muscle from the first two samples (I, 20 ppb; XV, 40 ppb), the major alkanes being C_{15} and C_{17}. Muscle from the third specimen (XXIX), however, contained 16 ppm of pristane. This sample also contained elevated levels of *n*-C_{29} and *n*-C_{31}. There was no clear evidence for petroleum contamination in any of these samples. Livers from the first two samples contained only 2.28 (II) and 2.71 (XVI) ppm, but the third (XXX) contained 542 ppm of alkanes. The C_{27} to C_{31} alkanes in sample XXX were probably petroleum derived.

Diplectrum bivittatum (dwarf sand perch)

The muscle (XLI) and liver (XLII) contained, respectively, 140 ppb and 1 ppm of biogenic alkanes.

Echeneis naucrates (sharksucker)

The dominant alkanes in the muscle (XCIII) of this fish were petroleum derived. The major hydrocarbon in the liver (XCIV) was pristane.

Haemulon aurolineatum (tom tate)

The muscle (LXXVI) of this fish contained petroleum alkanes, while the liver (LXXVII) did not contain hydrocarbons.

Kythoses incisor (yellow chum)

Two specimens were obtained in the vicinity of the production platform. The hydrocarbons in the muscle samples (LXVI, LXVIII) were dominated by $\underline{n}$-C_{17} and pristane, while the hydrocarbons in the liver samples (LXVII, LXIX) were dominated by pristane. One muscle (LXVIII, Fig. 23) and one liver (LXVII) contained petroleum alkanes, but these samples were from different fish.

Lagodon rhomboides (pinfish)

The muscle (XCII) of this specimen, obtained from the control well jacket, contained petroleum alkanes in the C_{21} to C_{31} region. Pristane, however, composed 32% of the total hydrocarbon content.

Menticirrhus americanus (southern kingfish)

The muscle (VII) and liver (VIII) tissue contained 275 ppb and 1.5 ppm, respectively, of alkanes. The C_{22} to C_{26} alkanes may have been petroleum derived.

Micropogon undulatus (Atlantic croaker)

Muscle from two specimens and a liver from one of them were examined. Muscle from the first sample (XXVI) contained 120 ppb of biogenic alkanes, whereas muscle from the second specimen (XLV) contained only petroleum-like alkanes. Liver from the second sample (XLVI) contained 790 ppb of alkanes of which 550 ppb (C_{22} to C_{30}) may be petroleum derived.

Ogocephalus parvus (roughback batfish)

The muscle (XXXV) contained 70 ppb and the liver (XXXVI) contained 1.6 ppm of $\underline{n}$-alkanes. There was no clear evidence of petroleum contamination.

Opsanus pardus (leopard toadfish)

The muscle tissue (LVIII) contained 66 ppb of alkanes, of which 24 ppb (C_{23} to C_{27}) may be petroleum derived. The liver (LIX) contained 870 ppb of alkanes, probably biogenic and dominated by pristane.

Orthopristis chrysoptera (pigfish)

In muscle (XLIII) and liver (XLIV) from one specimen, the predominant hydrocarbons were $\underline{n}$-C_{15} and $\underline{n}$-C_{17}. A second specimen, caught near the production platform contained 2.2 ppm of C_{25} to C_{31} alkanes in the liver (LV), but the muscle sample (LIV) did not contain hydrocarbons.

Peprilus burti (Gulf butterfish)

The muscle tissue (XLVII) contained 1.75 ppm of alkanes, principally pristane, C_{15}, and C_{19}. There were no petroleum alkanes. The liver was not examined.

Pomatomus saltratrix (bluefish)

Three specimens were examined. Muscle from all three (XXII, XXIV, LXXVIII) contained principally n-C_{15} and n-C_{17}; however, the C_{20}-C_{30} alkanes exhibited a typical petroleum-like distribution. One liver (LXXIX) did not contain hydrocarbons, but the other two samples (XXIII, XXV) contained petroleum distributions similar to the muscle samples.

Porichthys porosissimus (Atlantic midshipman)

The muscle (XX) contained 1.6 ppm of biogenic alkanes, principally C_{15}, pristane, and C_{17}. The liver (XXI; total alkanes, 23 ppm) also contained large amounts of n-C_{15} and n-C_{17}, but the C_{21} to C_{27} alkanes (10 ppm) were petroleum derived.

Prionotus ophryas (bandtail searobin)

The muscle tissue (XLIX) contained only 30 ppb of C_{15} to C_{18} alkanes. The liver was not examined.

Prionotus rubio (blackfin searobin)

Two specimens were analyzed. Muscle from the first (III) contained only 100 ppb of biogenic alkanes, whereas muscle from the second (XVII) contained 3.8 ppm of alkanes. The C_{23} to C_{27} alkanes may have been petroleum derived. Liver from the first (IV) contained only n-C_{21} whereas that from the second (XVIII) contained 22 ppm of alkanes, dominated by C_{15}. There was no clear evidence for petroleum contamination.

Saurida brasiliensis (largescale lizardfish)

The major alkanes from muscle of this specimen (XXXI; total alkanes, 170 ppb) were C_{15} and C_{17}, but the C_{22} to C_{30} petroleum alkanes were present. The liver (XXXII) contained 24 ppm of alkanes, dominated by C_{15} and pristane. There was no evidence for petroleum contamination.

Scorpaena calcarata (smoothhead scorpionfish)

The muscle (XLVIII) contained 80 ppb of biogenic alkanes, and the liver was not examined.

Serranus subligarus (belted sand bass)

The muscle (LXXXV) from this specimen, caught near the satellite well jacket, contained 0.59 ppm of alkanes, with possible petroleum contamination in the C_{22} to C_{28} region.

Stenotomus caprinus (longspine porgy)

The muscle (XIX) contained 840 ppb of alkanes, mainly pristane, C_{15}, and C_{17}. The C_{21} to C_{25} alkanes may be petroleum derived. The liver was not examined.

Syacium papillosum (dusky flounder)

All of the alkanes (C_{20} to C_{31}) in the muscle (LI) are probably petroleum derived. It is also likely that the C_{23} to C_{31} alkanes in the liver (LII) are from petroleum.

Symphurus plagiusa (blackcheek tonguefish)

The muscle (LIII) from this specimen was heavily contaminated with petroleum alkanes. It is probable that most, if not all, of the n-alkanes were petroleum derived. The liver was not examined.

Synodus foetens (inshore lizardfish)

Two specimens were examined. The muscle samples (IX, XI) contained 1.4 and 2.5 ppm, respectively of alkanes, principally C_{15}, C_{17}, and pristane. The C_{20} to C_{27} alkanes of the first sample exhibited the typical petroleum-like distribution. Muscle from the second specimen was uncontaminated. Liver samples (X, XII) contained 140 ppb and 1.3 ppm, respectively, of alkanes, dominated by C_{15}. There was no clear evidence for petroleum contamination in the livers of either specimen.

Urophycis floridanus (southern hake)

It is possible that the C_{24} to C_{26} alkanes in the muscle (XXXVII) were petroleum derived. There is clearer evidence that the C_{22} to C_{28} alkanes in the liver (XXXVIII) resulted from petroleum contamination.

Summary

It appears that blennies contain a biogenic hydrocarbon level, which is elevated in samples from the production platform, presumably due to petroleum production activities. Only two specimens of sheepshead (Archosargus probatocephalus) from the production platform were examined, and the data were insufficient to determine whether the alkanes in these samples were due to petroleum. The majority of spadefish (Chaetodipterus faber) from the production platform contained petroleum alkanes. This was also true for red snapper samples (Lutjanus campechanus). Despite petroleum contamination, the dominant hydrocarbons were still the biogenic alkanes C_{17}, C_{15}, and pristane. These fish appear to obtain more biogenic hydrocarbons, either through biosynthesis or ingestion, than petroleum hydrocarbons.

There was good evidence for petroleum alkanes in C. spilopterus, C. arenarius, M. undulatus, P. saltratrix, P. porosissimus, P. rubio, S. brasiliensis, S. caprinus, S. papillosum, S. plagiusa, S. foetens, and U. floridans. It was also possible that A. felis and O. pardus were contaminated, but there were no petroleum alkanes in the other species examined. Levels of petroleum alkanes were usually higher in livers than in muscle tissue. However, the biogenic hydrocarbons n-C_{15}, n-C_{17}, and pristane were usually present in larger concentrations than the petroleum hydrocarbons.

SUMMARY

The goals of this research project were fourfold:

1. to determine what compounds were being discharged from any structures associated with oil production activities;
2. to assess which, if any, of these compounds were present in the study area environment and biota;
3. to establish, if pollution were present, what area it encompassed;
4. to correlate the data and construct a model of the environmental effects of offshore oil production.

The major source of petroleum in the study area is the produced water discharged from the production platform. The major compounds measured in the discharged brine are the C_{12} to C_{36} alkanes, pristane, phytane, sulfur, and various low molecular weight aromatic compounds. The mean daily rate of brine discharge is 200 bbl (31,800 l), and the average daily oil discharge is 525 g (95 g of alkanes). Approximately 15 kg of sulfur are also discharged daily. While the average odd-even preference (OEP) ratio for the discharged brine is 0.99, the individual values vary from 0.58 to 1.52. The mean values for the n-heptadecane/pristane ratio and the n-octadecane/phytane ratio for the discharged brine are 1.05 and 2.44, respectively. These values are consistent with values obtained for Buccaneer crude oil (n-heptadecane/ pristane, 0.90; n-octadecane/phytane, 2.44). When the discharged brine is exposed to elevated temperatures, preferential evaporation of the lighter components (weathering). occurs. The average n-heptadecane/pristane ratio for brine stored in a brine separator tank a 21°C is 1.19, while the average n-octadecane/phytane ratio is 3.57. The same ratios for a tank at 30°C, where more evaporation of lower molecular weight alkanes would be likely to occur, are 1.11 (n-heptadecane/pristane) and 3.03 (n-octadecane/phytane).

Another possible source of pollution, the sewage discharge, was also evaluated. The alkanes present in this sample did not resemble the discharged brine or crude oil, but appeared to be biogenic compounds from bacteria or feces.

Bottom and surface water samples collected at locations within 200 m of the production platforms contained petroleum alkanes in concentrations up to 80 ppb. Surface water collected around the perimeter of production platform B also contained trace amounts of methylnaphthalenes and benzo[a]pyrene. n-Heptadecane/pristane and n-octadecane/phytane ratios in various samples were within the range of ratios obtained from the discharged brine, thus the source of petroleum in water within 200 m of the platform is Buccaneer crude oil.

Sediment samples obtained at distances up to 200 m from the production platform also contained petroleum alkanes. Concentrations decreased as distances from the platform increased. Methylnaphthalenes, benzo[a]pyrene, and sulfur were also present in thses samples, but these compounds did not exhibit concentration gradients. The n-heptadecane/pristane and n-octadecane/phytane ratios for these samples approximate the ratios for the discharged brine.

Examination of biota associated with the production platforms also revealed measurable levels of pollution. Invertebrates associated with barnacle shells (hydroids and corals) contained alkanes in the C_{22} to C_{32} region. Analysis for benzo[a]pyrene and methylnaphthalenes revealed that these compounds were present in samples collected in the vicinity of the production platform. If pristane and phytane were present, the appropriate ratios were strikingly different from the ratios seen in discharged brine. Corals contain alkanes in the C_{22} to C_{32} region (Koons et al., 1965), so it is probable that a portion of these compounds are biogenic. A few of the molluscs (Pteria colymbus) attached to the barnacle shells contained alkanes. The carcinogen data, however, indicate that all of these fauna were polluted by petroleum hydrocarbons.

The flesh and shells of barnacles attached to the production platform contained biogenic and petroleum alkanes. The biogenic compounds, n-C_{15}, n-C_{17}, n-C_{21}, and pristane, were usually the dominant hydrocarbons. In most samples, pristane accounted for 50% of the total hydrocarbon content. It was not possible, therefore, to rely upon n-heptadecane/pristane ratios or n-octadecane/phytane ratios to determine the source of the hydrocarbons. In fact, a casual perusal of the data could lead to the conclusion that these samples were not polluted. The samples contained alkanes in the C_{22} to C_{32} region which indicated the presence of petroleum. This was supported by the presence of methylnaphthalenes and benzo[a]pyrene.

The surface plankton caught in the vicinity of the platform contained up to 52 ppm of petroleum hydrocarbons, while subsurface plankton samples contained as the dominant hydrocarbons n-C_{15}, n-C_{17}, and pristane. The petroleum in surface plankton samples was attributed to tar balls. Due to the extensive weathering of the oil, and to the fact that pristane was often present in large amounts, n-heptadecane/pristane ratios and n-octadecane/phytane ratios could not be used to determine whether the petroleum was derived from Buccaneer crude oil.

Shrimp from the vicinity of the production platform contained petroleum hydrocarbons in low concentration. Since pristane and phytane were not present, the source of the hydrocarbons could not be ascertained. None of the samples contained benzo[a]pyrene, but a few did contain methylnaphthalenes.

The fish caught in the vicinity of the production platform are habitat sessile. Blennies, spadefish, and red snapper contained petroleum alkanes and biogenic hydrocarbons. In most samples, the biogenic hydrocarbons predominated, thus obviating the usefulness of OEP ratios, n-heptadecane/pristane ratios, and n-octadecane/phytane ratios for determining whether petroleum was present, and if so, the source of contamination.

Hydrocarbons are discharged in the produced brine into the seawater; biota, either filter-feeders, carnivores, or herbivores, ingest these compounds. If the appropriate enzymes are present, some hydrocarbons will be degraded or altered to facilitate urinary excretion. Other compounds will not be altered and will be incorporated into feces. These feces can be ingested by other fauna, thus continuing the chain of contamination in biota, or can be incorporated into the sediments. Again, ingestion by biota, such as bacteria or bottom-dwelling benthics, can occur, accompanied by additional alteration of the compounds. Hydrocarbons can also be adsorbed onto particulates such as sulfur. After discharge of sulfur, the same cycle can occur after ingestion by filter-feeders. Otherwise sulfur can be incorporated directly into sediments, thus providing nutrients for benthic biota.

There is no consistent pattern of pollution beyond a distance of 200 m from the production platform. Some water samples collected at distances up to 10 km from the center of the oilfield contained petroleum alkanes up to a maximum concentration of 35 ppb. Due to extensive weathering of the hydrocarbons, it could not be determined whether the petroleum was a product of Buccaneer oil production activities or of the freighter traffic and trawler activity in the area. When surface and bottom water samples were collected from the same locations, alkane concentrations were greatest downstream in the prevailing bottom current. Most of the bottom water samples exhibited a bimodal hydrocarbons distribution. Alkanes around C_{20} exhibited a distribution characteristic of petroleum alkanes, while the major components, around C_{33}, were of bacterial origin (Davis, 1968; Albro, 1976).

Sediments collected at various stations from the study area contained hydrocarbon profiles resembling those of other recent marine sediments in the Gulf of Mexico (Stevens *et al.*, 1956). A few random samples contained petroleum alkanes from C_{22} to C_{32}, but the source of the petroleum could not be determined.

Few of the subsurface plankton samples contained hydrocarbons other than *n*-C_{15}, *n*-C_{17}, and pristane. Several of the surface plankton samples contained petroleum hydrocarbons. One sample from the area of the satellite well jacket contained petroleum alkanes and tar balls.

Shrimp and squid caught in regions of the study area other than adjacent to the production platforms did not contain petroleum alkanes or carcinogens.

Barnacles and other invertebrates attached to the satellite well jacket structures were also examined for their hydrocarbon content. Few of the samples contained petroleum hydrocarbons. Most of the barnacle shells, which have hydroids and corals attached, contained alkanes from C_{22} to C_{32}. For these species, these compounds appeared to be biogenic, especially since levels of these compounds from biota attached to the production platforms were higher.

Migratory fish did not contain petroleum alkanes in most cases. If they were exposed to petroleum from the production platform, this would only be a transient experience. The fish could excrete or metabolize these compounds easily, so that it would be difficult to detect petroleum in biota exposed to chronic low levels of hydrocarbons for short periods of time. Some species of fish obtained from the vicinity of the well jackets are habitat sessile, yet they contained petroleum alkanes in the muscle samples. These most likely were adsorbed from the water.

The major conclusions from this study are:

1. There is petroleum contamination of water in this area of the Gulf of Mexico (Fig. 24), but beyond 0.2 km of the production platform this contamination cannot be ascribed to Buccaneer oilfield production activities.

2. Biota and sediments outside of the immediate vicinity of the production platforms do not contain petroleum hydrocarbons. This is especially important since this could affect the commercial fishing industry in the area.

3. For the analysis of trace amounts of petroleum alkanes in biota, OEP values, *n*-heptadecane/pristane ratios and *n*-octadecane/phytane ratios have low utility for the recognition of pollution and the source of petroleum.

BIBLIOGRAPHY

Ackman, R. G. Pristane and Other Hydrocarbons in Some Freshwater and Marine Fish Oils. Lipids 6, 520(1971).

Adlard, E. R., L. F. Creaser, P. H. D. Matthews. Identification of Hydrocarbon Pollutants on Seas and Beaches. Analytical Chemistry 44, 64 (1972).

Albro, P. W. Bacterial Hydrocarbons and Metabolism. Lipids 5, 320(1969).

Albro, P. W. "Bacterial Waxes" in P. E. Kolattukudy, Ed., Chemistry and Biochemistry of Natural Waxes. Amsterdam: Elsevier, 1976.

Albro, P. W. and C. K. Huston. Lipids of Sarcina Lutea. II. Hydrocarbon Content of the Lipid Extracts. Journal of Bacteriology 88, 981(1964).

Anderson, J. W. Personal Communication, 1976.

Anonymous. Houston Post, March 26, 1978.

Avigan, J. and M. Blumer. On the Origin of Pristane in Marine Organisms. Journal of Lipid Research 9, 350(1968).

Barbier, M., D. Joly, A. Saliot, and D. Tourres. Hydrocarbons from Sea Water. Deep Sea Research 20, 305(1973).

Bean, R. M., J. W. Blaylock, E. A. Sutton, R. E. Wildung, and F. M. Davidson. "Characterization of Sediments in the Vicinity of Offshore Petroleum Production" in T. F. Yen, Ed., Chemistry of Marine Sediments. Ann Arbor: Ann Arbor Science Publishers, 1977.

Bentz, A. P. Oil Spill Identification. Analytical Chemistry 48, 454A(1976).

Blumer, M. "Dissolved Organics Compounds in Sea Water. Saturated and Olefinic Hydrocarbons and Singly Branched Fatty Acids" in D. W. Hood, Ed., Organic Matter in Natural Waters. Alaska: University Press, 1970.

Blumer, M. Hydrocarbons in Digestive Tract and Liver of a Basking Shark. Science 156, 390(1967).

Blumer, M. "Oil Pollution of the Ocean" in D. P. Hoult, Ed., Oil on the Sea. New York: Plenum Press, 1969.

Blumer, M., T. Dorsey, and J. Sass. Azaarenes in Recent Marine Sediments. Science 195, 283(1977).

Blumer, M., M. Ehrhardt, and J. H. Jones. The Environmental Fate of Stranded Crude Oil. Deep Sea Research 20, 239(1973).

Blumer, M., R. R. L. Guillard, and T. Chase. Hydrocarbons of Marine Phytoplankton. Marine Biology 8, 183(1971).

Blumer, M., M. M. Mullin, and R. R. L. Guillard. A Polyunsaturated Hydrocarbon (3,6,9,12,15,18-heneicosahexaene) in the Marine Food Web. *Marine Biology*, *6*, 226(1970a).

Blumer, M., M. M. Mullin, and D. W. Thomas. Pristane in Zooplankton. *Science 140*, 974(1963).

Blumer, M., M. M. Mullin, and D. W. Thomas. Pristane in the Marine Environment. *Helgolander wiss. Meeresunters 10*, 187(1964).

Blumer, M., J. C. Robertson, J. E. Gordon, and J. Sass. Phytol-Derived C_{19} Di- and Triolefinic Hydrocarbons in Marine Zooplankton and Fishes. *Biochemistry 8*, 4067(1969).

Blumer, M. and J. Sass. Oil Pollution: Persistence and Degradation of Spilled Fuel Oil. *Science 176*, 1120(1972b).

Blumer, M. and W. D. Snyder. Isoprenoid Hydrocarbons in Recent Sediments: Presence of Pristane and Probable Absence of Phytane. *Science 150*, 1588(1965).

Blumer, M., G. Souza, and J. Sass. Hydrocarbon Pollution of Edible Shellfish by an Oil Spill. *Marine Biology 5*, 195(1970b).

Blumer, M. and D. W. Thomas. Phytadienes in Zooplankton. *Science 147*, 1148(1965a).

Blumer, M. and D. W. Thomas. "Zamene," Isomeric C_{19} Monoolefins from Marine Zooplankton, Fishes, and Mammals. *Science 148*, 370(1965b).

Blumer, M. and W. W. Youngblood. Polycyclic Aromatic Hydrocarbons in Soils and Recent Sediments. *Science 188*, 53(1975).

Boylan, D. B. and B. W. Tripp. Determination of Hydrocarbons in Seawater Extracts of Crude Oil and Crude Oil Fractions. *Nature 230*, 44(1971).

Botello, A. V. and E. F. Mandelli. Distribution of n-Paraffins in Sea-Grasses, Benthic Algae, Oysters and Recent Sediments from Terminos Lagoon, Campeche, Mexico. *Bulletin of Environmental Contamination and Toxicology 19*, 162(1978).

Bravo, H. A., S. L. Salazar, A. V. Botello, and E. F. Mandelli. Polyaromatic Hydrocarbons in Oysters from Coastal Lagoons along the Eastern Coast of the Gulf of Mexico, Mexico. *Bulletin of Environmental Contamination and Toxicology 19*, 171(1978).

Bray, E. E. and E. D. Davis. Distribution of n-Paraffins as a Clue to Recognition of Source Beds. *Geochim. Cosmochim. Acta 22*, 2(1961).

Brooks, J. M., B. B. Bernard, and W. M. Sackett. "Input of Low Molecular-Weight Hydrocarbons from Petroleum Operation in the Gulf of Mexico" in D. A. Wolfe, Ed., *Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms*. Elmsford, N.Y.: Pergamon Press, 1977.

Brooks, P. W., G. Eglinton, S. J. Gaskell, D. J. McHugh, J. R. Maxwell, and R. P. Philp. Lipids of Recent Sediments, Part I: Straight-Chain Hydrocarbons and Carboxylic Acids of Some Temperate Lacustrine and Sub-Tropical Lagoonal/Tidal Flat Sediments. Chemical Geology 18, 21 (1976).

Brown, R. A. and H. L. Huffman, Jr. Hydrocarbons in Open Ocean Waters. Science 191, 847(1976).

Brummage, K. G. "Sources of Oil Entering the Sea" in Background Papers, Workshop on Petroleum in Marine Environment. Ocean Affairs Board, National Academy of Sciences, Washington, D.C., 1973.

Burns, K. A. and J. M. Teal. Hydrocarbon Incorporation into the Salt Marsh Ecosystem from the West Falmouth Oil Spill. Bureau of Commercial Fisheries. Washington: Government Printing Office, 1971.

Burns, K. A. and J. M. Teal. Hydrocarbons in the Pelagic Sargassum Community. Deep Sea Research 20, 207(1973).

Clark, R. C. and M. Blumer. Distribution of n-Paraffins in Marine Organisms and Sediment. Limnology and Oceanography 12, 79(1967).

Clark, R. C. and J. S. Finley. Paraffin Hydrocarbon Patterns in Petroleum-Polluted Mussels. Marine Pollution Bulletin 4, 172(1973).

Cole, R. D. Recognition of Crude Oils by Capillary Gas Chromatography. Nature 233, 546(1971).

Dastillung, M. and P. Albrecht. Molecular Test for Oil Pollution in Surface Sediments. Marine Pollution Bulletin 7, 13(1976).

Davis, J. B. Paraffinic Hydrocarbons in the Sulfate-Reducing Bacterium Desulfovibrio desulfuricans. Chemical Geology 3, 155(1968).

Dell'Acqua, R., J. A. Egan and B. Bush. Identification of Petroleum Products in Natural Water by GC. Environmental Science and Technology 9, 38(1975).

DiSalvo, L. H., H. E. Guard and L. Hunter. Tissue Hydrocarbon Burden of Mussels as Potential Monitor of Environmental Hydrocarbon Insult. Environmental Science and Technology 9, 247(1975).

Dunn, B. P. and H. F. Stich. Release of the Carcinogen Benzo[a]pyrene from Environmentally Contaminated Mussels. Bulletin of Environmental Contamination and Toxicology 15, 398(1976).

Easton, R. Black Tide: The Santa Barbara Oil Spill and Its Consequences. New York: Delacorte Press, 1972.

Ehrhardt, M. Petroleum Hydrocarbons in Oysters from Galveston Bay. Environmental Pollution 3, 257(1972).

Ehrhardt, M. and M. Blumer. The Source Identification of Marine Hydrocarbons by GC. Environmental Pollution 3, 179(1972).

Ehrhardt, M. and J. Heinemann. Hydrocarbons in Blue Mussels from the Kiel Bight. *Environmental Pollution 9*, 263(1975).

Elder, D. L. and S. W. Fowler. Polychlorinated Biphenyls: Penetration into the Deep Ocean by Zooplankton Fecal Pellet Transport. *Science 197*, 459(1977).

Evans, E. D., G. S. Kenny, W. G. Meinschein, and E. E. Bray. Distribution of n-Paraffins and Separation of Saturated Hydrocarbons from Recent Marine Sediments. *Analytical Chemistry 29*, 1858(1957).

Farrington, J. W. and J. G. Quinn. Petroleum Hydrocarbons in Narragansett Bay I. Survey of Hydrocarbons in Sediments and Clams. *Estuarine and Coastal Marine Sciences 1*, 71(1973a).

Farrington, J. W. and J. G. Quinn. Petroleum Hydrocarbons and Fatty Acids in Wastewater Effluents. *Journal of the Water Pollution Control Federation 45*, 704(1973b).

Feuerstein, D. L. "Input of Petroleum to the Marine Environment" in Background Papers, Workshop on Petroleum in Marine Environment. Ocean Affairs Board, National Academy of Sciences, Washington, D.C., 1973.

Finucane, J. H. Personal Communication, 1977.

Fossato, V. V. and W. J. Canzonier. Hydrocarbon Uptake and Loss by the Mussel *Mytilus edulis*. *Marine Biology 36*, 243(1976).

Fotheringham, N. Personal Communication, 1977.

Fotheringham, N. and S. Brunenmeister. *Common Marine Invertebrates of the Northwestern Gulf Coast*. Houston. Gulf Publishing Co., 1975.

Gallaway, B. Personal Communication, 1978.

Garza, M. E. and J. Muth. Characterization of Crude, Semirefined and Refined Oils by Gas-Liquid Chromatography. *Environmental Science and Technology 8*, 249(1974).

Gaskell, S. J., R. J. Morris, G. Eglinton, and S.E. Calvert. The Geochemistry of a Recent Marine Sediment off Northwest Africa. An Assessment of Source Input and Early Diagenesis. *Deep Sea Research 22*, 777(1975).

Gearing, P., J. N. Gearing, T. F. Lytle, and J. S. Lytle. Hydrocarbons in 60 Northeast Gulf of Mexico Shelf Sediments: A Preliminary Survey. *Geochim. Cosmochim. Acta 40*, 1005(1976).

Gelpi, E., J. Oro, H. J. Schneider, and E. O. Bennett. Olefins of High Molecular Weight in Two Microscopic Algae. *Science 161*, 700(1968).

Gelpi, E., H. Schneider, J. Mann, and J. Oro. Hydrocarbons of Geochemical Significance in Microscopic Algae. *Phytochemistry 9*, 603(1970).

Giam, C. S., H. S. Chan, and G. S. Neff. Distribution of *n*-Paraffins in Selected Marine Benthic Organisms. *Bulletin of Environmental Contamination and Toxicology 16*, 37(1976).

Giger, W. and M. Blumer. Polycyclic Aromatic Hydrocarbons in the Environment: Isolation and Characterization by Chromatography, Visible, UV and MS. *Analytical Chemistry 46*, 1663(1974).

Giger, W., M. Reinhard, C. Schaffner, and W. Strumm. Petroleum-Derived and Indigenous Hydrocarbons in Recent Sediments of Lake Zug, Switzerland. *Environmental Science and Technology 8*, 454(1974).

Grimmer, G. and H. Bohnke. Profile Analysis of Polycyclic Aromatic Hydrocarbons and Metal Content in Sediment Layers of a Lake. *Cancer Letters 1*, 75(1975).

Grose, P. L. and J. S. Mattson. *The "Argo Merchant" Oil Spill*. National Oceanic and Atmospheric Administration. Boulder, Colorado: Government Printing Office, 1977.

Hallhagen, A. "Survey of Present Knowledge and Discussion of Input of Petroleum into the Marine Environment in Sweden" in Background Papers, Workshop on Petroleum in Marine Environment. Ocean Affairs Board, National Academy of Sciences, Washington, D.C., 1973.

Halsall, T. G. and I. R. Hills. Isolation of Heneicosa-1,6,9,12,15,18-hexaene and -1,6,9,12,15-pentaene from the Alga *Fucus vesiculosus*. *Chemical Communications* (1971), 448.

Hamilton, R. J., M. Y. Raie, I. Weatherston, C. J. Brooks, and J. H. Borthwick. Crustacean Surface Waxes. Part I. The Hydrocarbons from the Surface of *Ligia oceanica*. *JCS Perkin I*, 354(1975).

Han, J. and M. Calvin. Hydrocarbon Distribution of Algae and Bacteria and Microbiological Activity in Sediments. *Proceedings of the National Academy of Sciences 64*, 436(1969).

Han, J., E. D. McCarthy, and M. Calvin. Hydrocarbon Constituents of the Blue-Green Algae *Nostoc muscorum*, *Anacystis nidulans*, *Phormidium luridum* and *Chlorogleae fritschii*. *Journal Chemical Society (Part C)* (1968), 2785.

Han, J., E. D. McCarthy, W. Van Hoeven, M. Calvin, and W. H. Bradley. Organic Geochemical Studies. II A Preliminary Report on the Distribution of Aliphatic Hydrocarbons in Algae, in Bacteria and in a Recent Lake Sediment. *Proceedings of the National Academy of Sciences 59*, 29 (1968b).

Hardie, R., P. R. Mackie, K. J. Whittle, and A. D. McIntyre. Discrimination in the Assimilation of *n*-Alkanes in Fish. *Nature 252*, 577(1974).

Harper, D. E., R. J. Scrudato and C. S. Giam. *A Preliminary Assessment of the Buccaneer Oil/Gas Field*. National Marine Fisheries Service, Galveston, Texas, 1976.

Hites, R. A. and K. Biemann. Water Pollution: Organic Compounds in the Charles River, Boston. Science 178, 158(1972).

Hites, R. A., R. E. LaFlamme and J. W. Farrington. Sedimentary PAH: The Historical Record. Science 198, 829(1977).

Horn, M. H., J. M. Teal, and R. H. Backus. Petroleum Lumps on the Surface of the Sea. Science 168, 245(1970).

Iliffe, T. M. and J. A. Calder. Dissolved Hydrocarbons in the Eastern Gulf of Mexico Loop Current and the Caribbean Sea. Deep Sea Research 21, 481(1974).

Jackson, B. W., R. W. Judges, and J. L. Powell. Characterization of Australian Crudes and Condensates by GC Analysis. Environmental Science and Technology 9, 656(1975).

Jackson, W. B. (Ed.). Environmental Assessment of an Active Oilfield in the Northwestern Gulf of Mexico, 1976-1977. National Marine Fisheries Service, Galveston, Texas, 1977.

Johnson, R. A. and J. A. Calder. Early Diagenesis of Fatty Acids and Hydrocarbons in a Salt Marsh Environment. Geochim. Cosmochim. Acta 37, 1943(1973).

Knights, B. A., A. C. Brown, E. Conway, and B. S. Middleditch. Hydrocarbons from the Green Form of the Freshwater Algae Botyrococcus braunii. Phytochemistry 9, 1317 (1970).

Koons, C. B., G. W. Jamieson, and L. S. Cieresko. Normal Alkane Distributions in Marine Organisms; Possible Significance to Petroleum Origin. Bulletin of American Association of Petroleum Geologists 49, 301(1965).

Kvenvolden, K. A. Normal Paraffin Hydrocarbons in Sediments from San Francisco Bay, California. Bulletin of American Association of Petroleum Geologists 46, 1643(1962).

Lambertsen, G. and R. T. Holman. Partial Characterization of the Hydrocarbons of Herring Oil. Acta Chem. Scand. 17, 281(1963).

Ledet, E. J. and J. L. Laseter. Alkanes at Air-Sea Interface from Offshore Louisiana and Florida. Science 186, 261(1974).

Lee, R. F., J. C. Nevenzel, G. A. Paffenhofer, A. A. Benson, S. Patton, T. E. Kavanagh. An Unique Hexaene Hydrocarbon from a Diatom (Skeletonema costatum). Biochim. Biophys. Acta 202, 386(1970).

Lee, R. F., R. Sauerheber, and A. A. Benson. Petroleum Hydrocarbons: Uptake and Discharge by the Marine Mussel Mytilus edulis. Science 177, 344(1972).

Levy, E. M. and A. Walton. High Seas Oil Pollution: Particulate Petroleum Residues in the North Atlantic. Journal Fisheries Research Board of Canada 33, 2781(1976).

Lytle, T. F. and J. S. Lytle. Assessment of Hydrocarbon Pollutants in Gulf and Estuarine Environments. Journal of Mississippi Academy of Sciences 21, 128(1976).

Martin, L. Personal Communication, 1978.

Meinschein, W. G. Significance of Hydrocarbons in Sediments and Petroleum. Geochim. Cosmochim. Acta 22, 58(1961).

Merck Index. An Encyclopedia of Chemicals and Drugs, Ninth Edition. Rathaway, N.J.: Merck and Co., 1976.

Meyer, B. Sulfur, Energy and Environment. Amsterdam: Elsevier, 1977.

Moore, S. F. and R. L. Dwyer. Effects of Oil on Marine Organisms: A Critical Assessment of Published Data. Deep Sea Research 8, 819(1974).

Morgan, J. P., R. J. Menzies, S. J. El-Sayed, and C. H. Oppenheimer. The Offshore Ecology Investigation. Gulf Universities Research Consortium Report No. 138, September 1974.

National Academy of Sciences. Petroleum in the Marine Environment. Workshop on Inputs, Fates and the Effects of Petroleum in the Marine Environment. Washington, D.C., 1975.

Neff, J. M. and J. W. Anderson. An Ultraviolet Spectrophotometric Method for the Determination of Naphthalene and Alkyl-Naphthalenes in the Tissues of Oil-Contaminated Marine Animals. Bulletin Environmental Contamination Toxicology 14, 122(1975).

Neff, J. M., B. A. Cox, D. Dixit, and J. W. Anderson. Accumulation and Release of Petroleum-Derived Aromatic Hydrocarbons by Four Species of Marine Animals. Marine Biology 38, 279(1976).

Nelson-Smith, A. Oil Pollution and Marine Ecology. New York: Plenum Press, 1973.

Oro, J., T. G. Tornabene, D. W. Nooner, and E. Gelpi. Aliphatic Hydrocarbons and Fatty Acids of Some Marine and Freshwater Microorganisms. Journal of Bacteriology 96, 1811(1967).

Overton, E. B., J. Bracken, and J. L. Laseter. Application of Glass Capillary Columns to Monitor Petroleum-Type Hydrocarbons in Marine Sediments. Journal of Chromatographic Science 15, 169(1977).

Paffenhofer, G. A. Cultivation of Calanus helgolandicus under Controlled Conditions. Helgolander wiss. Meeresunters 20, 346(1970).

Paoletti, C., B. Pushparaj, G. Florenzo, P. Capella, and G. Lercker. Unsaponifiable Matter of Green and Blue-Green Algal Lipids as a Factor of Biochemical Differentiation of their Biomass: I. Total Unsaponifiable and Hydrocarbon Fraction. Lipids 2, 258(1976).

Peake, E. and G. W. Hodgson. Alkanes in Aqueous Systems. I. Exploratory Investigations on the Accommodation of C_{20}-C_{33} n-Alkanes in Distilled Water and Occurrence in Natural Water Systems. *Journal of American Oil Chemists Society 74*, 1773(1966).

Philippi, G. T. On the Depth, Time and Mechanism of Petroleum Generation. *Geochim. Cosmochim. Acta 29*, 1021(1965).

Sargent, J. R., R. F. Lee, and J. C. Nevenzel. "Marine Waxes" in P.E. Kolattukudy, Ed., *Chemistry and Biochemistry of Natural Waxes*. Amsterdam: Elsevier, 1976.

Shaw, D. G. Lipids in Shallow Bottom Sediments. *Environmental Science and Technology 7*, 740(1973).

Simoneit, B. R., D. H. Smith, G. Eglinton,and A. L. Burlingame. Application of Real-Time Mass Spectrometric Techniques to Environmental Organic Geochemistry II. Organic Matter in San Francisco Bay Area Water. *Archives of Environmental Contamination and Toxicology 1*, 193(1973).

Smith, H. M. Qualitative and Quantitative Aspects of Crude Oil Composition, Bulletin 642. Bureau of Mines. Washington, D.C.: Government Printing Office, 1968.

Stegeman, J. J. and J. M. Teal. Accumulation, Release and Retention of Petroleum Hydrocarbons by the Oyster, *Crassotrea virginia*. *Marine Biology 22*, 37(1973).

Stevens, N. P., E. E. Bray, and E. D. Evans. Hydrocarbons in Sediments of Gulf of Mexico. *Bulletin of American Association Petroleum Geologists 40*, 975(1956).

Storrs, P. N. "Inputs to the Marine Environment from Land Sources" in Background Papers, Workshop on Petroleum in Marine Environment. Ocean Affairs Board, National Academy of Sciences, Washington, D.C., 1973.

Straughan, D. *Effects of Natural Chronic Exposure to Petroleum in the Marine Environment*. American Petroleum Institute publication no. 4280, October, 1976.

Sumich, J. A. *Biology of Marine Life*. Dubuque, Iowa: Wm. C. Brown Co., 1976.

Sutton, C. and J. A. Calder. Solubility of Higher Molecular Weight n-Paraffins in Distilled Water and Seawater. *Environmental Science and Technology 8*, 654(1974).

Sweeley, C. C., W. H. Elliot, I. Fries, and R. Ryhage. Mass Spectrometric Determination of Unresolved Compounds in Gas Chromatographic Effluents. *Analytical Chemistry 38*, 1549(1966).

Travers, W. B. and P. R. Luney. Drilling, Tankers, and Oil Spills on the Atlantic Outer Continental Shelf. *Science 194*, 791(1976).

Voss, M. Personal Communication, 1977.

Wakeham, S. G. and R. Carpenter. Aliphatic Hydrocarbons in Sediments of Lake Washington. Limnology and Oceanography 21, 711(1976).

Warner, J. S. Determination of Aliphatic and Aromatic Hydrocarbons in Marine Organisms. Analytical Chemistry 48, 578(1976).

Winters, K., P. L. Parker, and C. Van Baalen. Hydrocarbons of Blue-Green Algae: Gochemical Significance. Science 163, 467(1969).

Wilson, R. D., P. H. Monaghan, A. Asanik, L. C. Price and M. A. Rogers. "Estimated of Annual Input of Petroleum to the Marine Environment from Natural Marine Seepage" in Background Papers, Workshop on Petroleum in Marine Environment. Ocean Affairs Board, National Academy of Sciences, Washington, D.C., 1973.

Youngblood, W. W. and M. Blumer. Alkanes and Alkenes in Marine Benthic Algae. Marine Biology 21, 163(1973).

Youngblood, W. W. and M. Blumer. Polycyclic Aromatic Hydrocarbons in the Environment: Homologous Series in Soils and Recent Marine Sediments. Geochim. Cosmochim. Acta 39, 1303(1975).

Youngblood, W. W., M. Blumer, R. R. L. Guillard and F. Fiore. Saturated and Unsaturated Hydrocarbons in Marine Benthic Algae. Marine Biology 8, 190(1971).

Zafiriou, O. C. Improved Method for Characterizing Environmental Hydrocarbons by GC. Analytical Chemistry 45, 952(1973).

APPENDIX

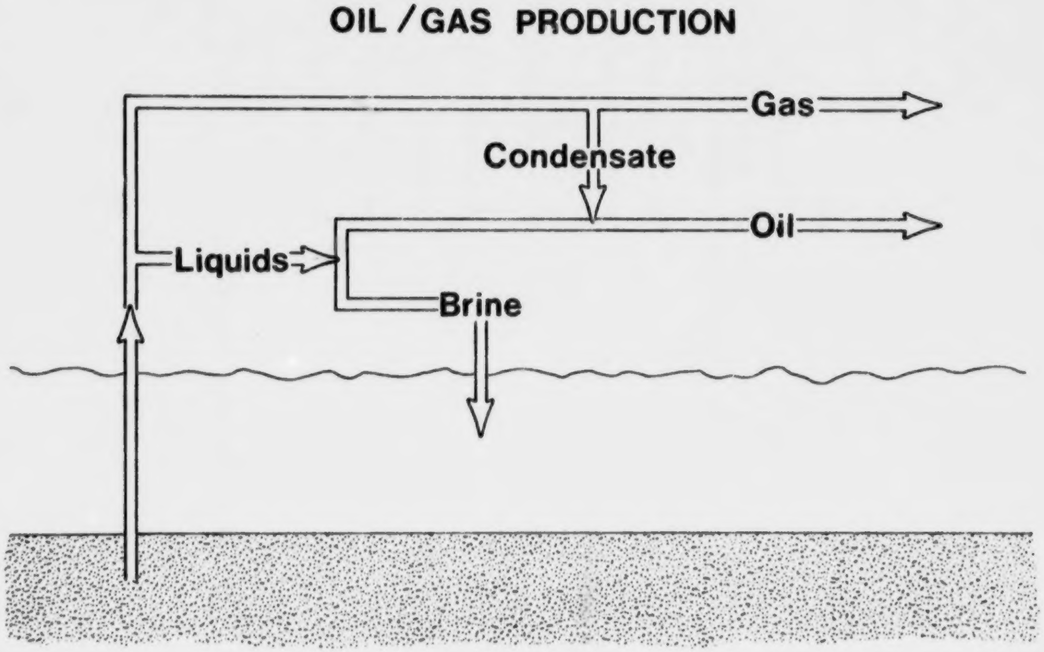

OIL / GAS PRODUCTION
Gas
Condensate
Oil
Liquids
Brine

Fig. 1 Schematic representation of the separation of oil and gas from brine.

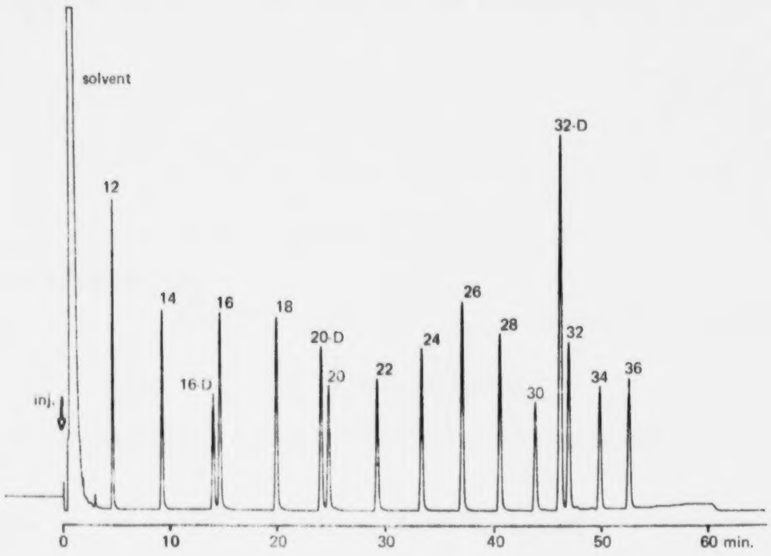


Fig. 2 Gas chromatogram showing separation of n-[$^2H_{34}$]hexadecane (16-D), n-[$^2H_{42}$]eicosane (20-D), and n-[$^2H_{66}$]dotriacontane (32-D) from n-alkanes $C_{12}H_{26}$ (12) to $C_{36}H_{74}$ (36). 6 ft x 2mm (i.d.) glass column containing 1% OV-1 on Supelcoport (100-120 mesh), programmed from 100 to 300° at 4° per min.

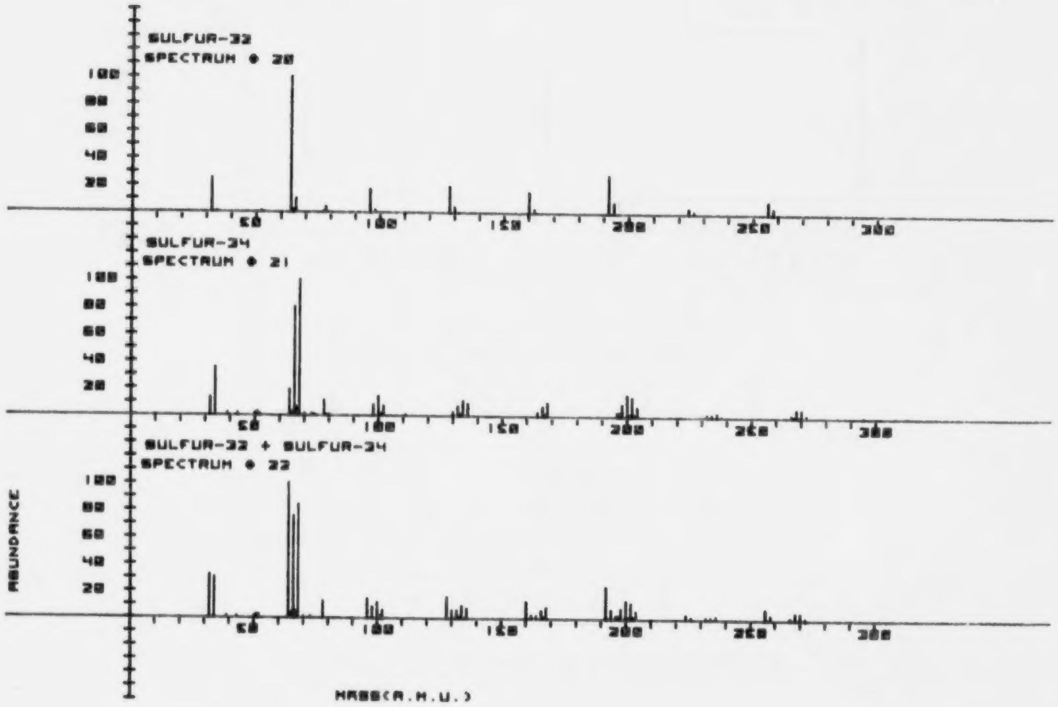


Fig. 3 Mass spectra of natural sulfur (upper), sulfur enriched in sulfur-34 (middle), and a mixture of the two (lower).

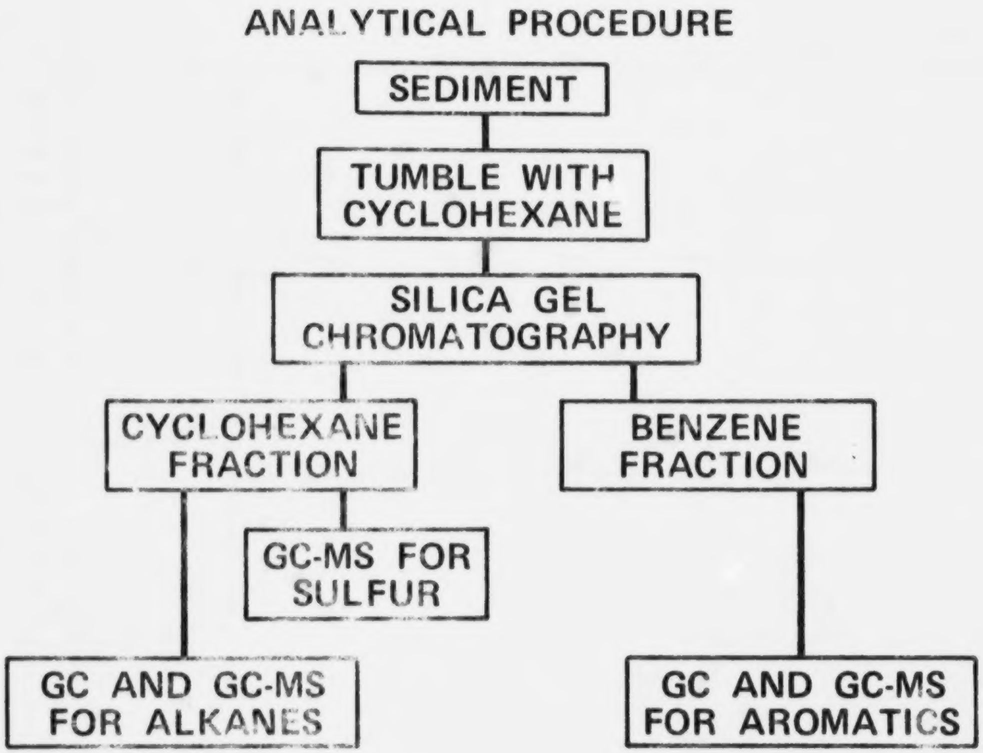

ANALYTICAL PROCEDURE
SEDIMENT
TUMBLE WITH CYCLOHEXANE
SILICA GEL CHROMATOGRAPHY
CYCLOHEXANE FRACTION
BENZENE FRACTION
GC-MS FOR SULFUR
GC AND GC-MS FOR ALKANES
GC AND GC-MS FOR AROMATICS

Fig. 4 Integrated analytical procedure for alkanes, aromatic hydrocarbons, and sulfur, illustrated for sediments.

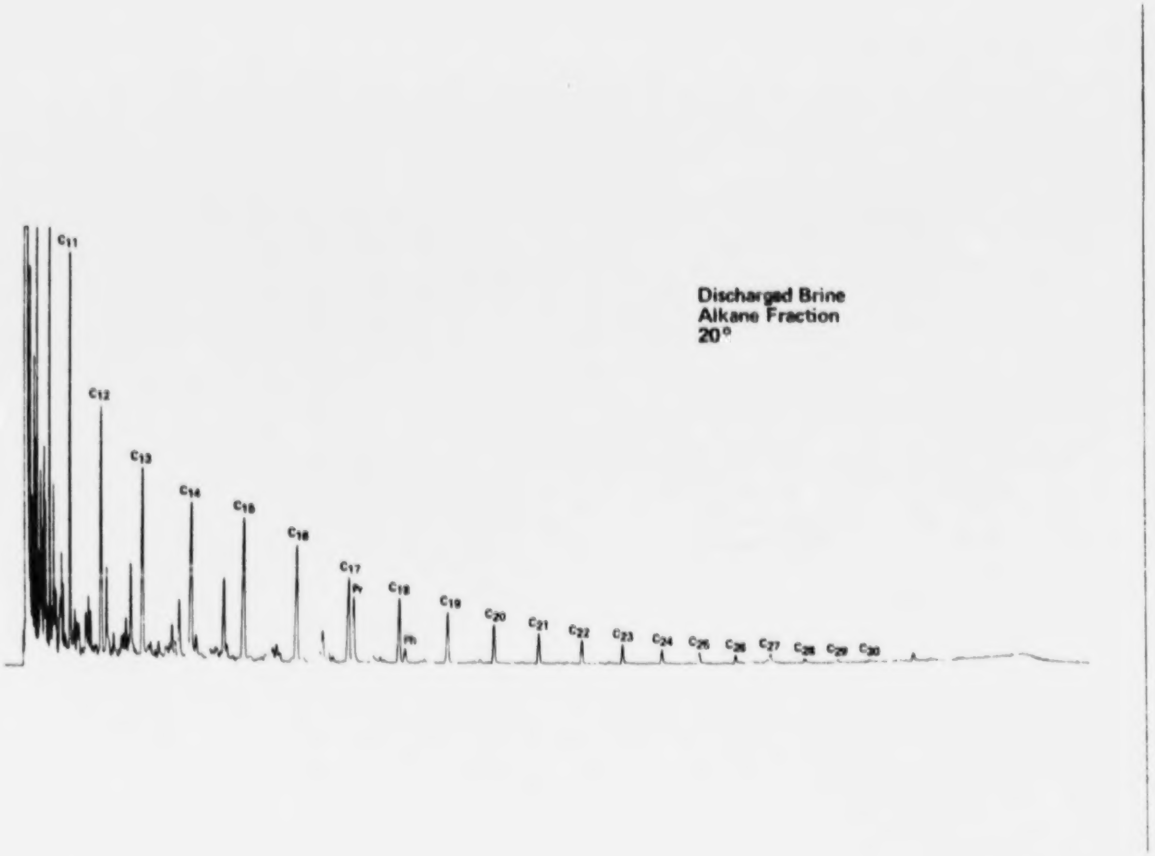


Fig. 5 Gas chromatogram for alkane fraction of brine discharged from Platform B on March 8, 1977 at 21°C.

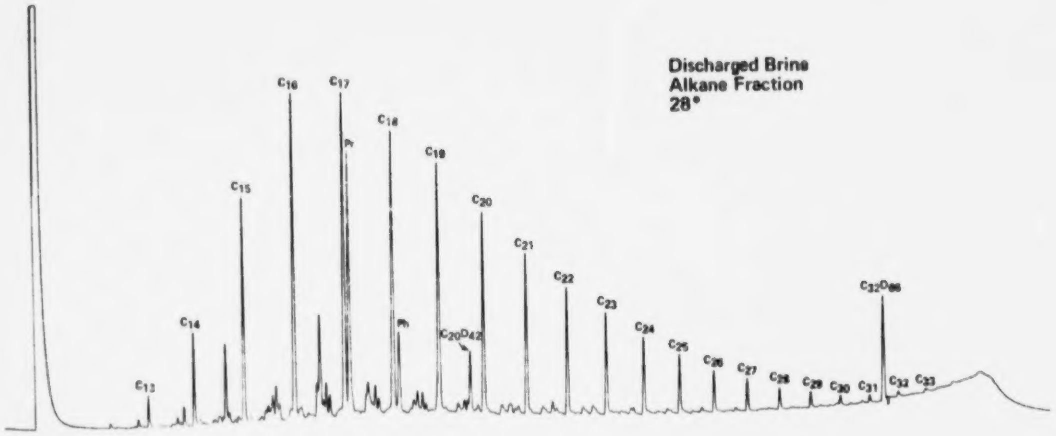


Fig. 6 Gas chromatogram for alkane fraction of brine discharged from Platform A on March 8, 1977 at 30°C.

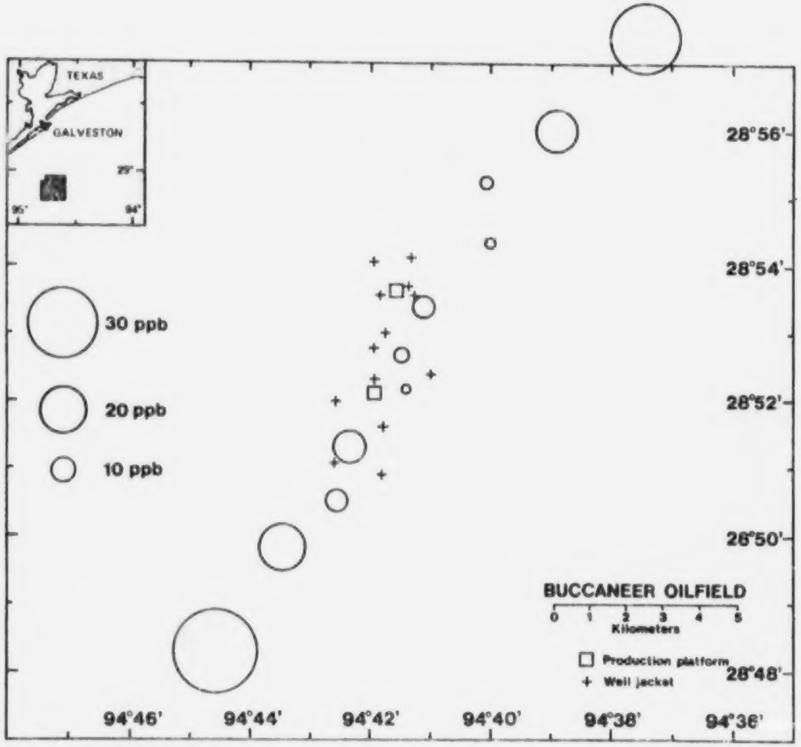

TEXAS
GALVESTON
29°
95°
94°
30 ppb
20 ppb
10 ppb
28°56'
28°54'
28°52'
28°50'
28°48'
94°46'
94°44'
94°42'
94°40'
94°38'
94°36'
BUCCANEER OILFIELD
0 1 2 3 4 5
Kilometers
□ Production platform
+ Well jacket

Fig. 7 Alkane concentrations in surface water samples collected August 31-September 1, 1976.

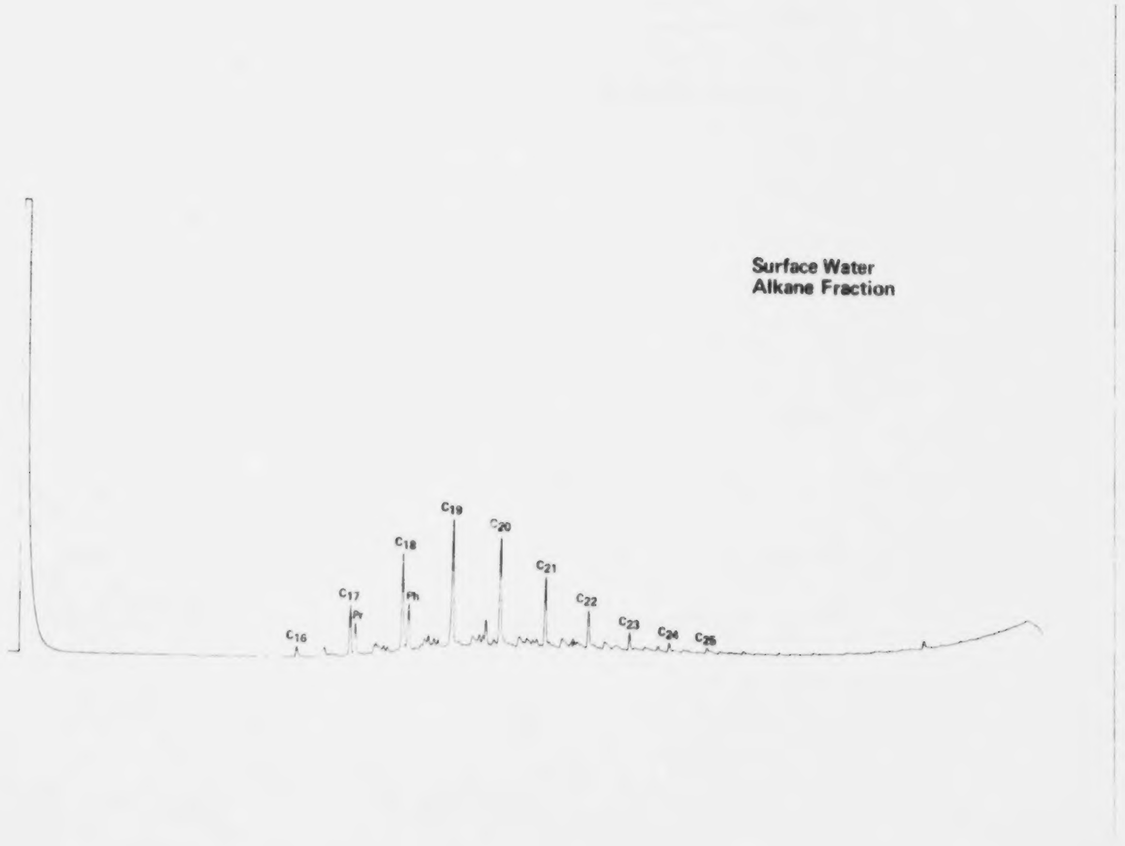


Fig. 8 Gas chromatogram for alkane fraction of surface water sample collected August 31-September 1, 1976.

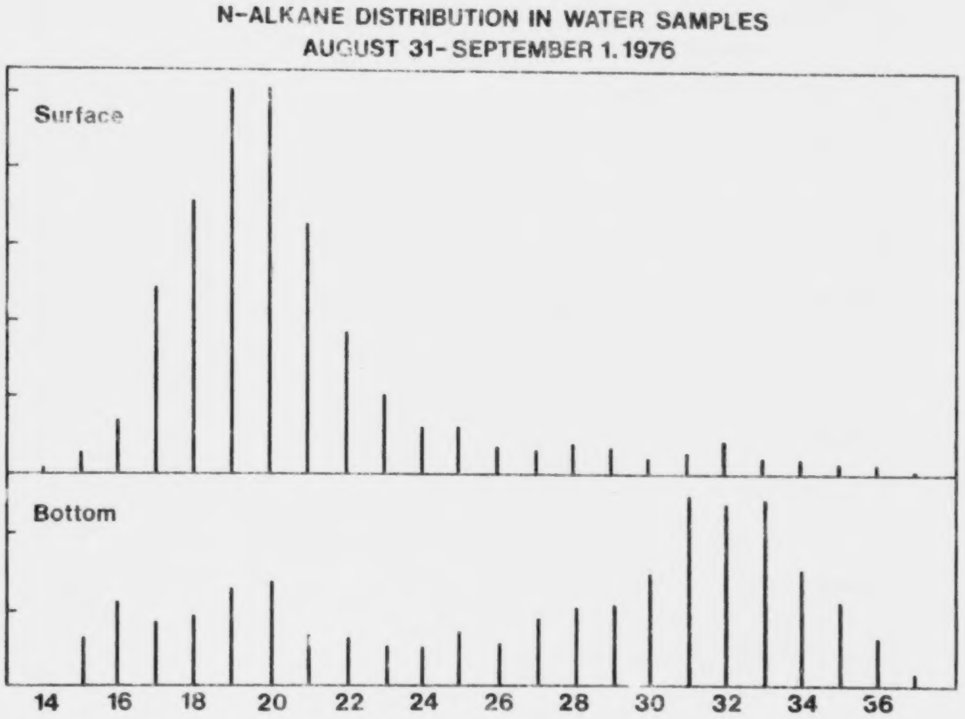
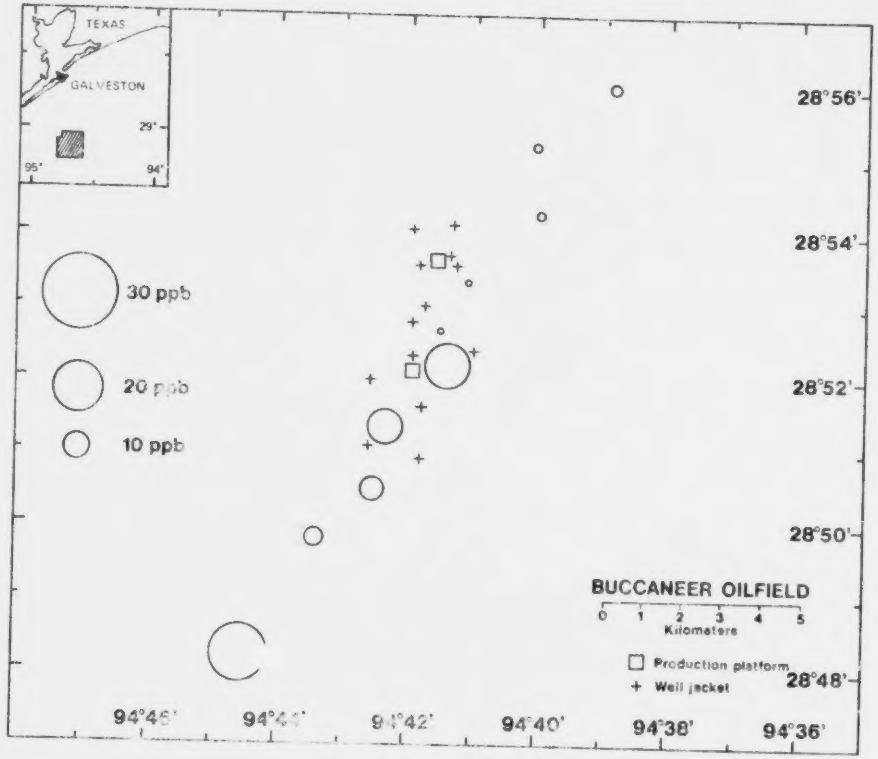


Fig. 9 Alkane profiles for surface and bottom water samples collected August 31-September 1, 1976.


TEXAS
GALVESTON
29°
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28°48'
BUCCANEER OILFIELD
0 1 2 3 4 5
Kilometers
□ Production platform
+ Well jacket
94°46'
94°44'
94°42'
94°40'
94°38'
94°36'

Fig. 10 Alkane concentrations in bottom water samples collected August 31-September 1, 1976.

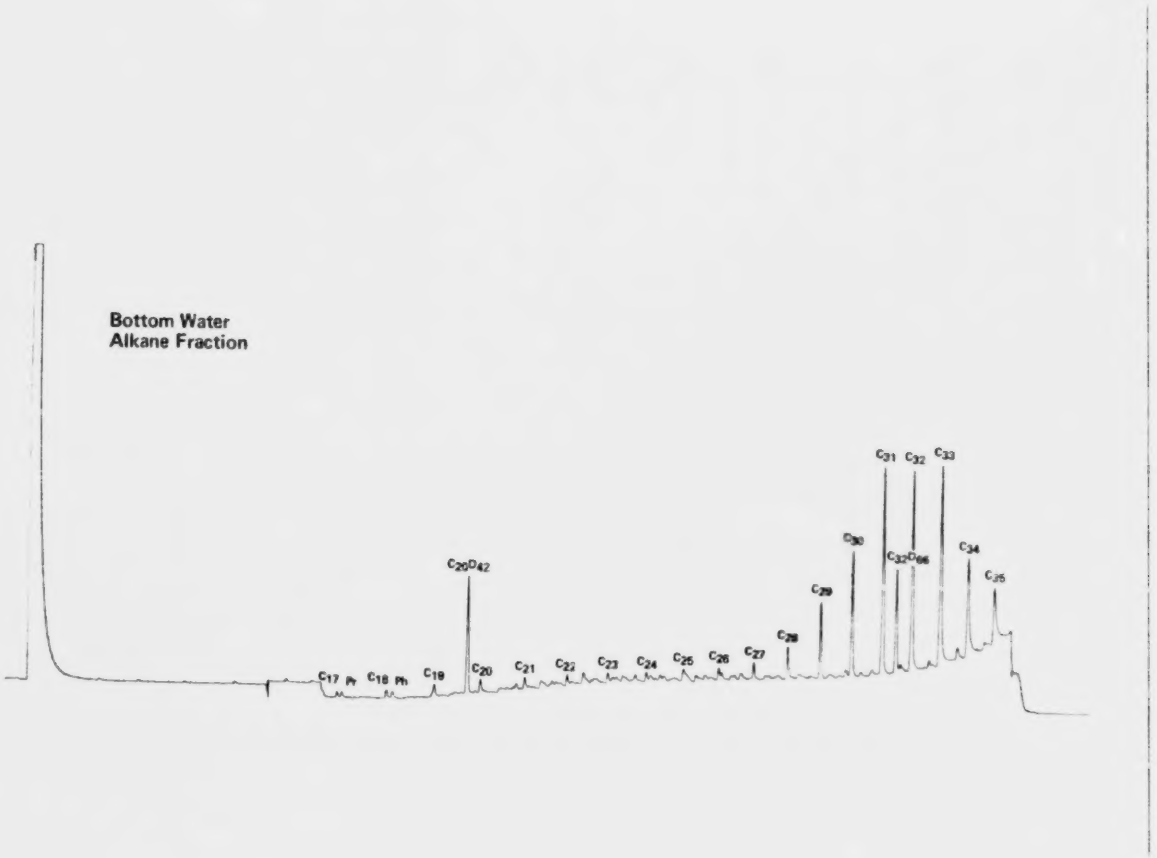


Fig. 11 Gas chromatogram for alkane fraction of bottom water sample collected August 31-September 1, 1976.

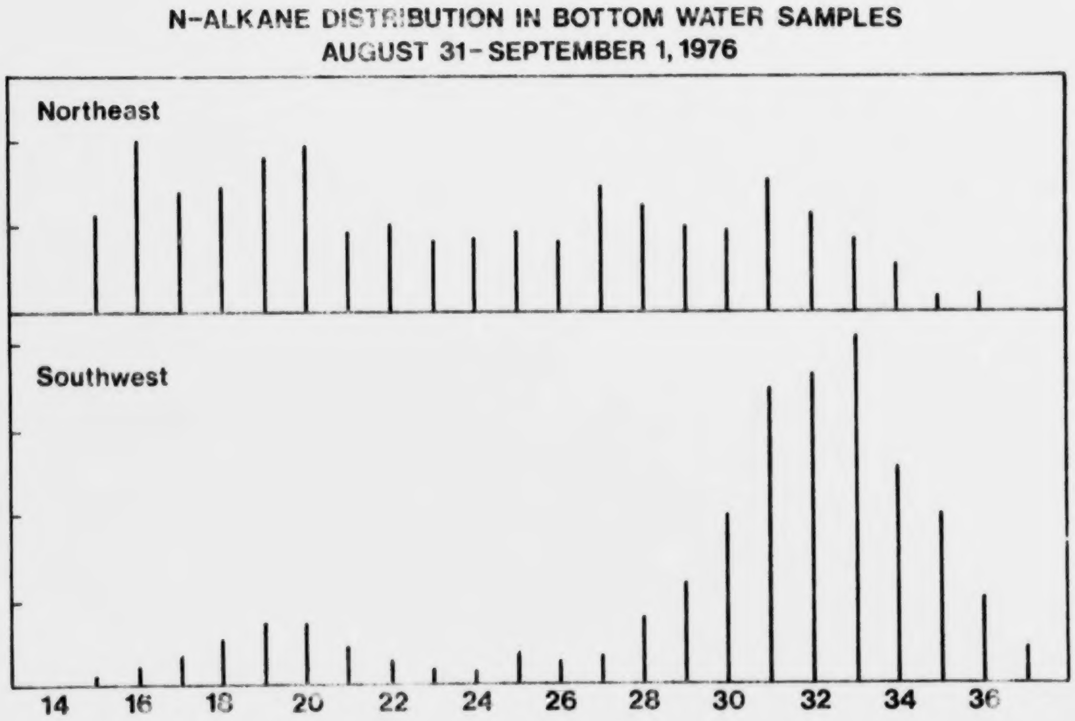
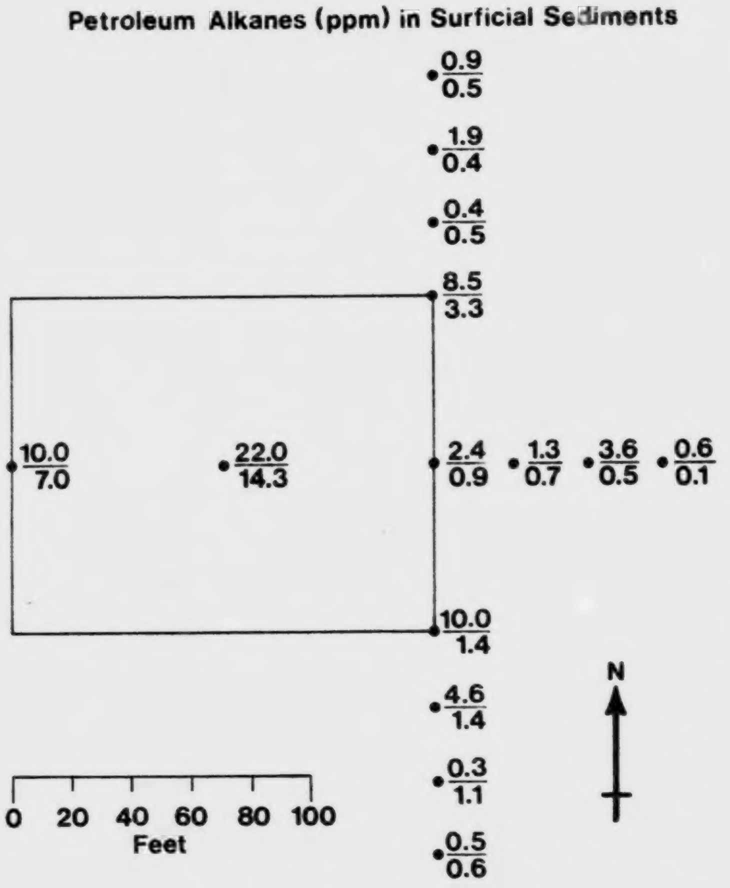


Fig. 12 Alkane profiles for bottom water samples collected August 31-September 1, 1976 from the SW and NE quadrants of the study area.



Petroleum Alkanes (ppm) in Surficial Sediments

0.9/0.5
1.9/0.4
0.4/0.5
8.5/3.3
10.0/7.0
22.0/14.3
2.4/0.9
1.3/0.7
3.6/0.5
0.6/0.1
10.0/1.4
4.6/1.4
0.3/1.1
0.5/0.6
N
0
20
40
60
80
100
Feet

Fig. 13 Alkane distributions in surficial sediment samples in the vicinities of production platforms. For each site, concentrations are given for Platform A (upper) and Platform B (lower).

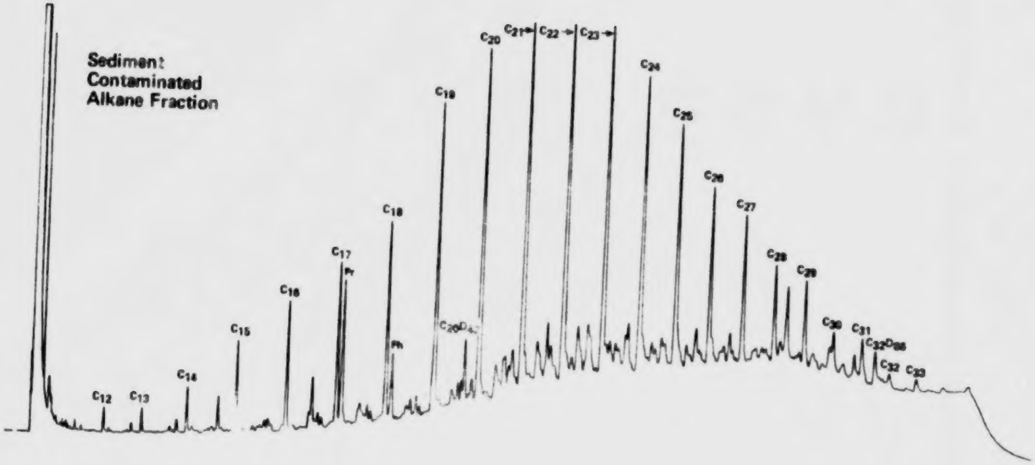


Fig. 14 Gas chromatogram for alkane fraction of surficial sediment sample containing fresh oil.

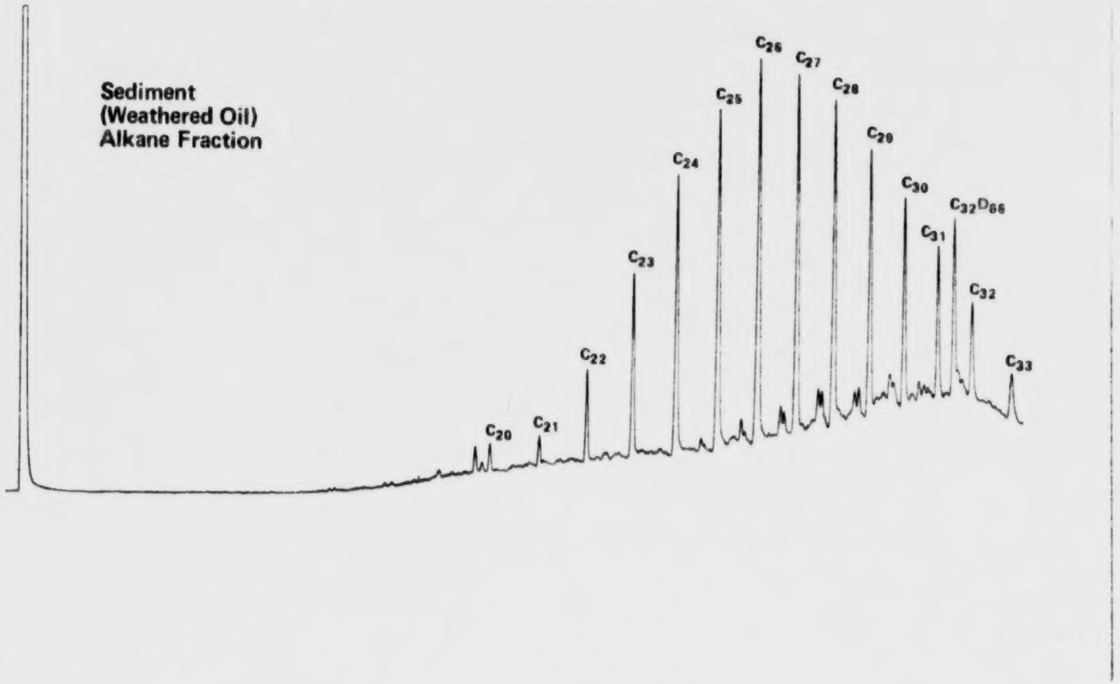


Fig. 15 Gas chromatogram for alkane fraction of surficial sediment sample containing weathered oil.

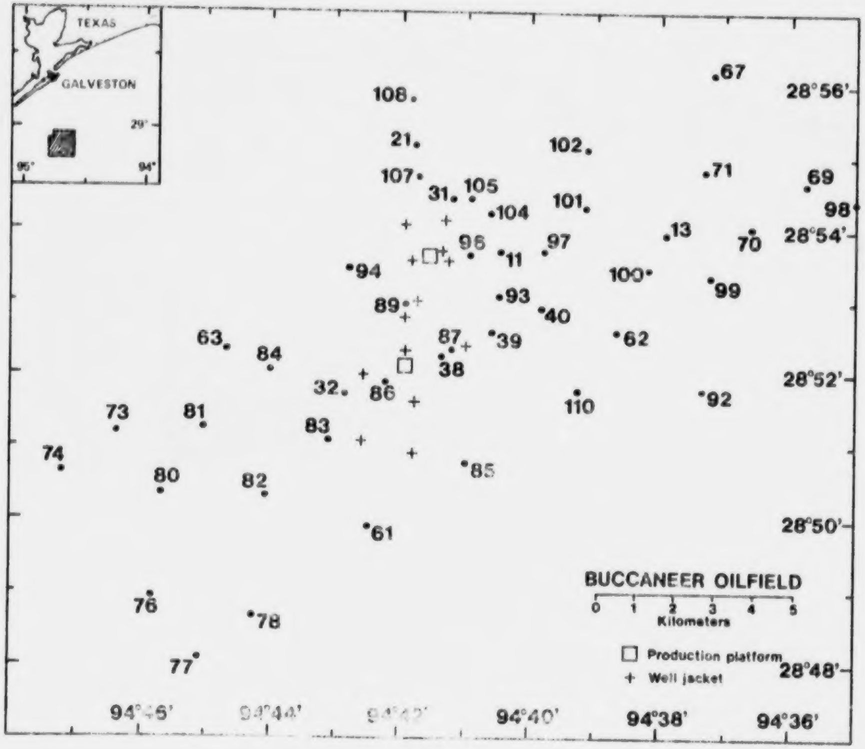

TEXAS
GALVESTON
29°
95°
94°
108
21
102
67
28°56'
107
31
105
104
101
71
69
98
96
11
97
13
70
28°54'
94
100
99
89
93
40
63
84
87
39
62
38
32
86
28°52'
92
110
73
81
83
74
85
80
82
61
28°50'
BUCCANEER OILFIELD
0
1
2
3
4
5
Kilometers
76
78
☐ Production platform
+ Well jacket
77
28°48'
94°46'
94°44'
94°42'
94°40'
94°38'
94°36'

Fig. 16 Sample sites for some sediment and water samples collected during 1976-77.

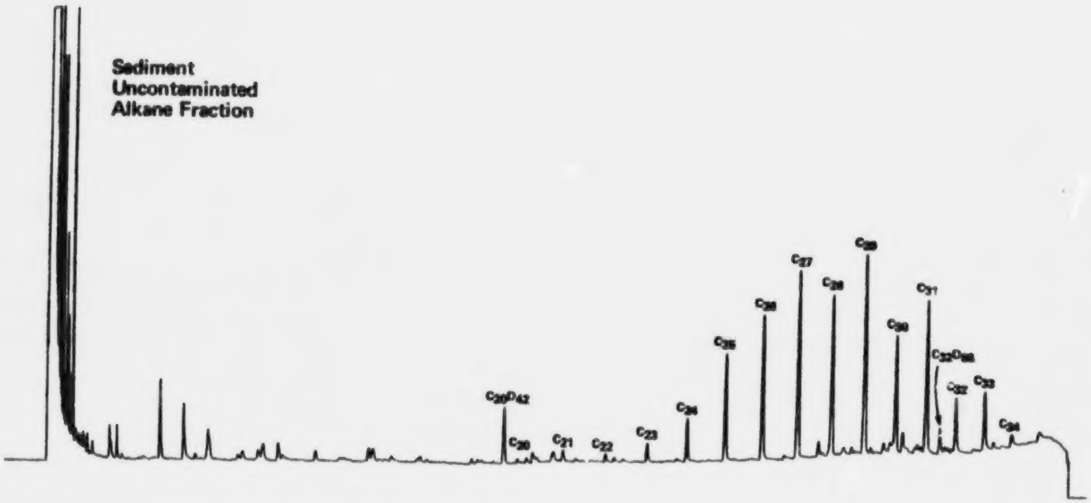


Fig. 17 Gas chromatogram for alkane fraction of surficial sediment containing biogenic hydrocarbons.

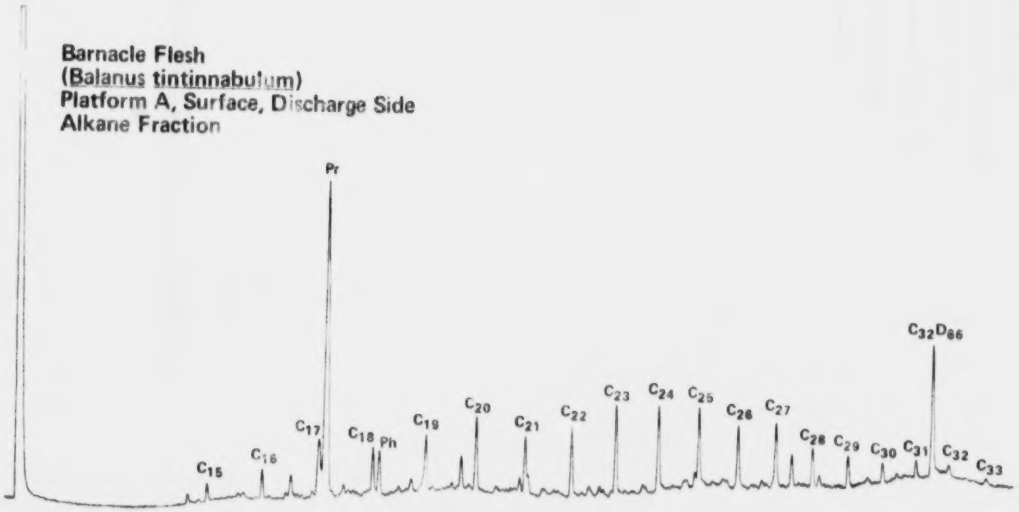


Fig. 18 Gas chromatogram for alkane fraction of flesh of barnacle (Balanus tintinnabulum).

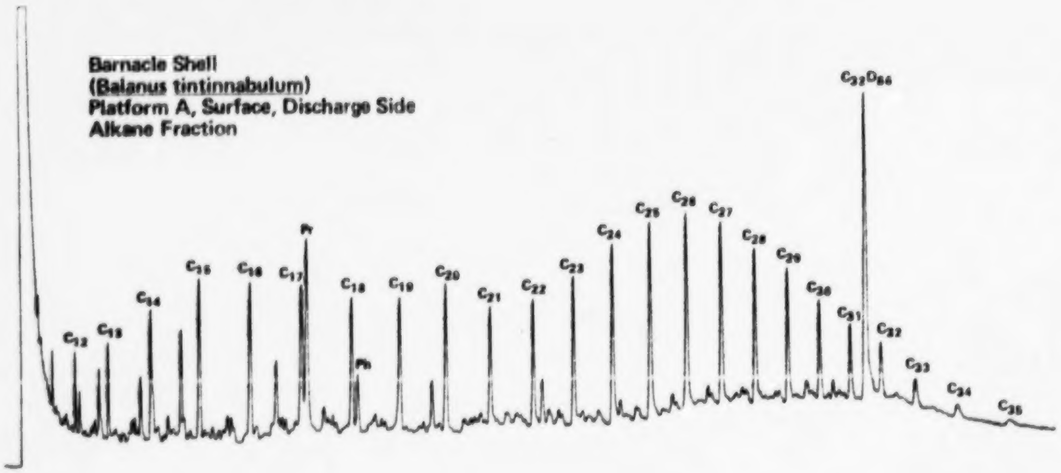


Fig. 19 Gas chromatogram for alkane fraction of shell (including attached biota) of barnacle (Balanus tintinnabulum).

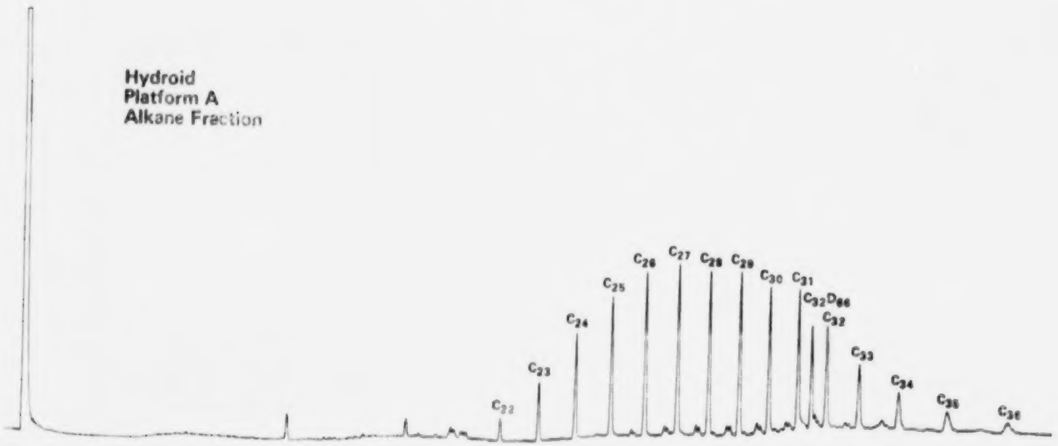


Fig. 20 Gas chromatogram for alkane fraction of a hydroid.

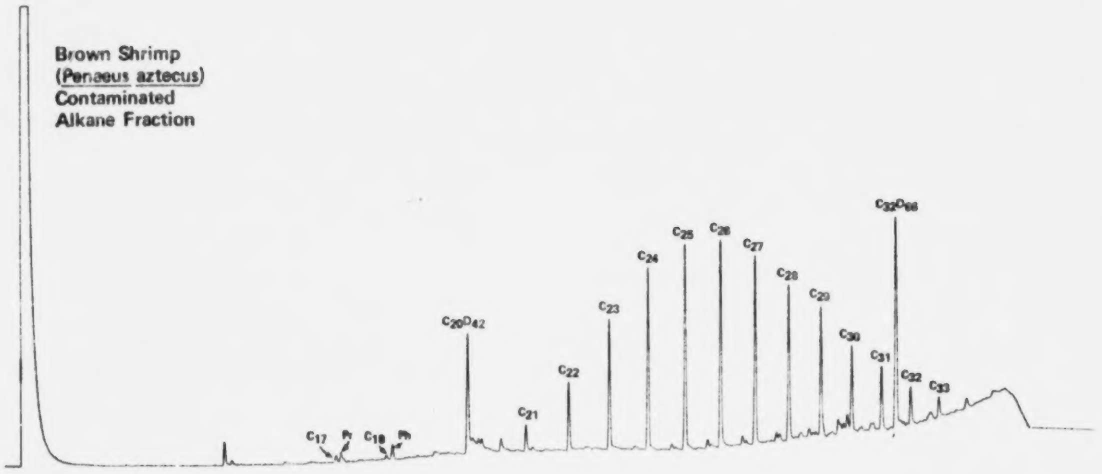


Fig. 21 Gas chromatogram for alkane fraction of contaminated brown shrimp (Penaeus aztecus).

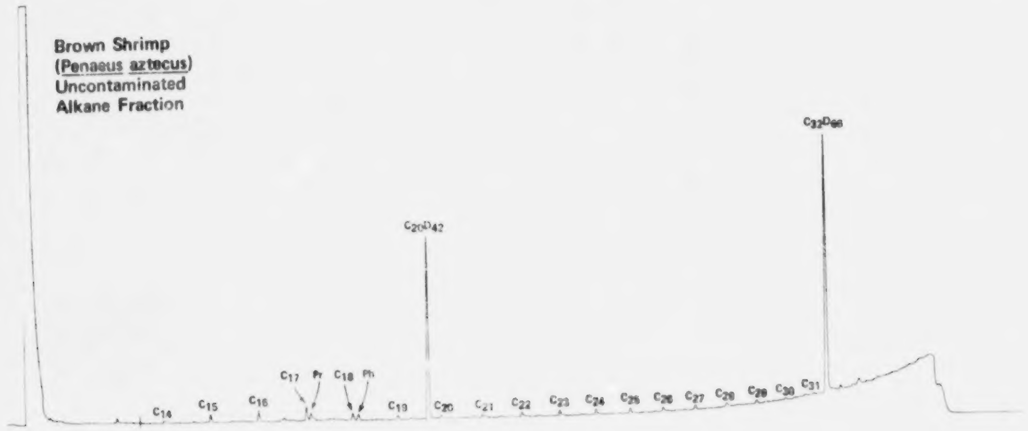


Fig. 22 Gas chromatogram for alkane fraction of uncontaminated brown shrimp (Penaeus aztecus).

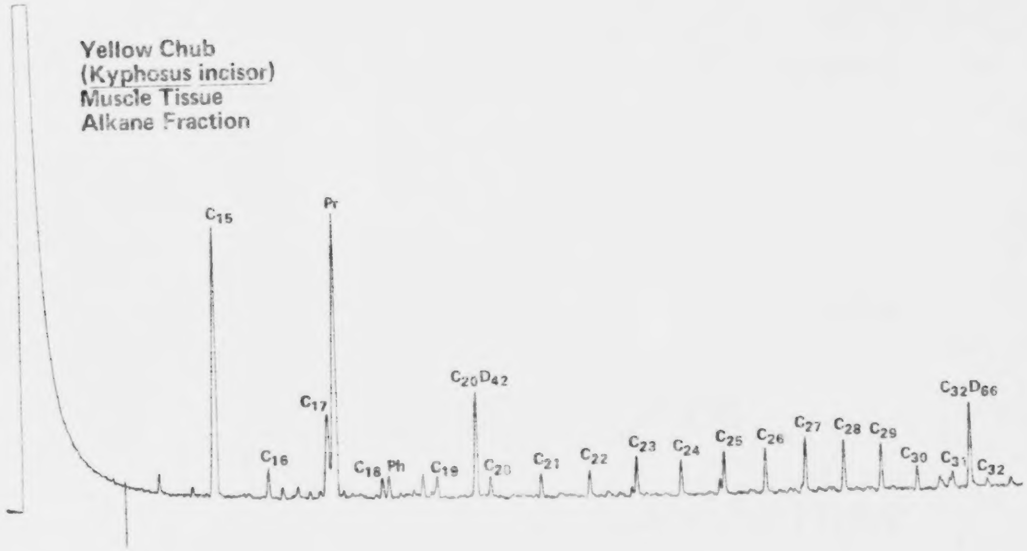


Fig. 23 Gas chromatogram for alkane fraction of flesh sample from yellow chum (Kythoses incisor).

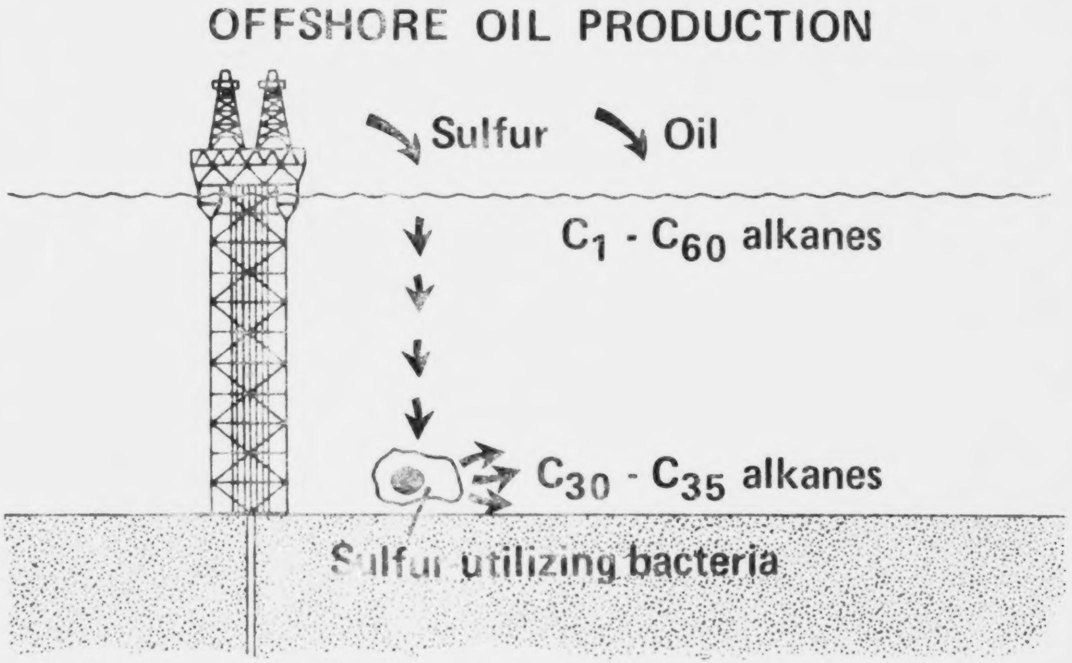

OFFSHORE OIL PRODUCTION
Sulfur
Oil
C_1 - C_{60} alkanes
C_{30} - C_{35} alkanes
Sulfur utilizing bacteria

Fig. 24 Schematic representation of alkanes in the water column resulting from (a) direct discharge, and (b) biosynthesis by sulfur-utilizing bacteria.

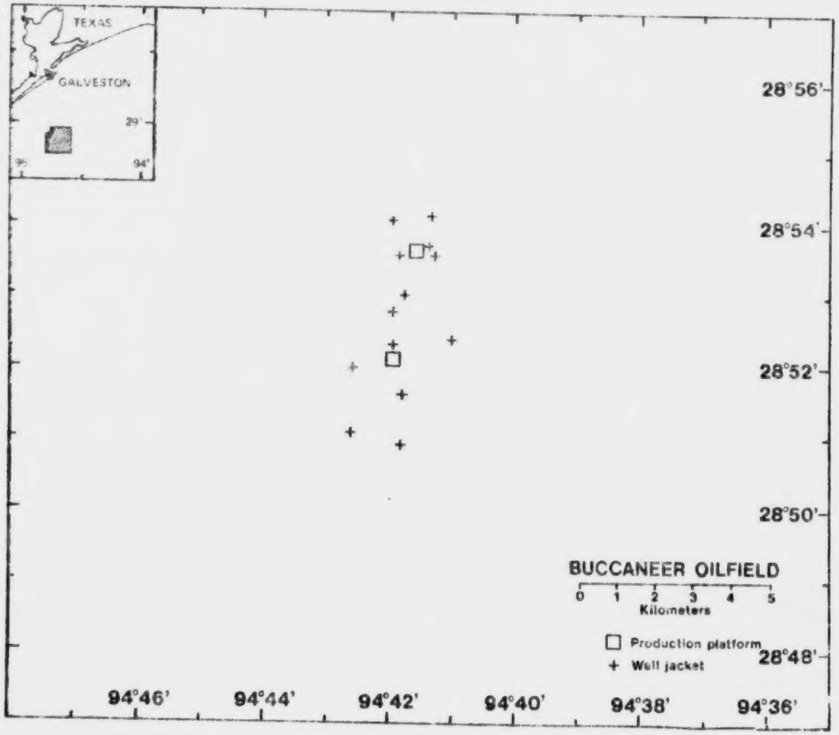

TEXAS
GALVESTON
29°
95°
94°
28°56'
28°54'
28°52'
28°50'
28°48'
94°46'
94°44'
94°42'
94°40'
94°38'
94°36'
BUCCANEER OILFIELD
0 1 2 3 4 5
Kilometers
□ Production platform
+ Well jacket

Fig. 25 Alphanumeric grid used to describe the sources of some samples collected in the study area.

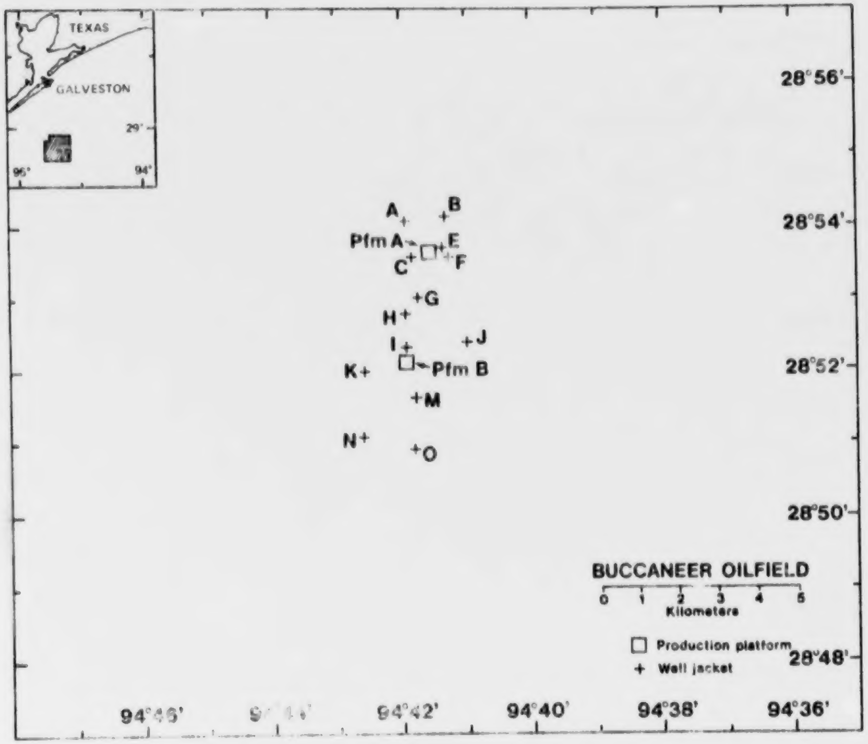

TEXAS
GALVESTON
29°
95°
94°
A
B
Pfm A
E
C
F
G
H
I
J
K
Pfm B
M
N
O
28°56'
28°54'
28°52'
28°50'
28°48'
BUCCANEER OILFIELD
0 1 2 3 4 5
Kilometers
☐ Production platform
+ Well jacket
94°46'
94°44'
94°42'
94°40'
94°38'
94°36'

Fig. 26 Locations of structures in the Buccaneer oilfield.

TABLES

TABLE 1

TABULATION OF PLATFORM SAMPLES

Sample	Date	Platform	Description
I	4-21-76	A	crude oil
II	4-21-76	A	condensate
III	4-21-76	A	discharged brine
IV	7-16-76	B	crude oil
V	7-16-76	B	condensate
VI	7-16-76	B	discharged brine
VII	9-25-76	B	discharged brine
VIII	10-30-76	B	discharged brine
IX	12-17-76	A	discharged brine
X	12-17-76	A	discharged brine
XI	12-17-76	B	discharged brine
XII	01-30-77	A	discharged brine
XIII	01-30-77	B	discharged brine
XIV	02-01-77	A	discharged brine
XV	02-01-77	B	discharged brine
XVI	03-08-77	B	discharged brine (1300)
XVII	03-08-77	B	discharged brine (1400)
XVIII	03-08-77	B	discharged brine (1500)
XIX	03-08-77	B	discharged brine (1600)
XX	03-08-77	A	discharged brine (1415)
XXI	03-08-77	A	discharged brine (1515)
XXII	03-08-77	A	discharged brine (1615)
XXIII	03-08-77	A	discharged brine (1715)
XXIV	6-26-77	B	discharged brine
XXV	6-26-77	A	discharged brine
XXVI	7-15-77	B	discharged brine
XXVII	7-15-77	A	discharged brine
XXVIII	8-21-77	B	discharged brine
XXIX	8-21-77	A	discharged brine
XXX	9-18-77	B	discharged brine
XXXI	9-18-77	A	discharged brine
XXXII	10-23-77	B	discharged brine
XXXIII	10-23-77	A	discharged brine
XXXIV	11-14-77	B	discharged brine
XXXV	12-22-77	B	discharged brine
XXXVI	1-29-78	B	discharged brine
XXXVII	2-5-78	B	discharged brine (1400)
XXXVIII	2-5-78	B	discharged brine (1600)

TABLE 2

DISTRIBUTION OF n-ALKANES IN PLATFORM SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12	1.3	27.3	19.9	14.5	50.4	0.9	0
C-13	1.7	21.2	14.7	13.3	25.2	6.0	
C-14	3.8	16.8	12.8	12.3	13.0	11.2	
C-15	20.7	14.7	11.6	12.3	6.5	13.8	
C-16	17.2	9.6	8.8	10.3	3.1	12.1	
C-17	12.1	5.4	6.9	7.6	1.2	10.3	
C-18	9.7	2.9	4.8	6.1	0.5	8.6	
C-19	8.2	1.4	4.1	5.6	0.2	6.0	
C-20	6.0	0.5	3.3	4.2	0.1	5.2	
C-21	4.6	0.2	2.7	3.3	4.3		
C-22	3.7	0.1	2.2	2.7	3.4		
C-23	3.0		1.9	2.1	3.4		
C-24	2.3		1.4	1.6	1.7		
C-25	1.8		1.4	1.3	1.7		
C-26	1.2		0.9	0.9	3.4		
C-27	0.9		0.8	0.7	1.7		
C-28	0.6		0.7	0.4	1.7		
C-29	0.5		0.7	0.3	1.7		
C-30	0.3		0.5	0.2	0.9		
C-31	0.2			0.1	0.9		
C-32	0.2			0.1	0.9		
C-33	0.1			0.1			
C-34	0.1						
C-35							
C-36							
C-37							

TABLE 2 (continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12							
C-13			8.1	10.6		6.3	
C-14		1.5	12.5	16.7	5.4	12.5	
C-15	12.3	1.5	14.0	16.3	8.1	12.5	
C-16	23.4	5.9	14.0	13.9	11.5	18.8	1.8
C-17	18.3	11.8	12.5	10.6	14.2	31.3	9.2
C-18	12.9	17.6	9.6	8.0	13.1		12.7
C-19	10.2	11.8	7.4	6.1	13.1	6.3	15.9
C-20	6.6	17.6	5.9	4.7	9.6	12.5	14.1
C-21	4.8	2.9	3.7	3.2	8.1		12.4
C-22	3.6	5.9	2.9	2.7	6.5		10.6
C-23	2.4		2.2	1.9	4.6		8.8
C-24	1.5	2.9	1.5	1.3	2.7		7.1
C-25	1.5	2.9	1.5	0.9	1.9		4.4
C-26	0.9	5.9	1.1	0.9	1.2		1.8
C-27	0.6	1.5	0.4	0.4			0.9
C-28	0.3			0.4			0.4
C-29	0.3	1.5		0.2			
C-30	0.1	1.5	0.4	0.2			
C-31	0.1	1.5	0.2	0.2			
C-32	0.1	1.5	0.2	0.4			
C-33		1.5	0.7	0.1			
C-34		2.9	0.4	0.2			
C-35							
C-36							
C-37							

TABLE 2 (continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12				21.6		9.3	
C-13		27.8	21.6	26.6	10.2	1.0	0.9
C-14	17.8	16.7	12.3	22.8	20.8	3.1	2.6
C-15	18.3	15.6	11.7	13.6	22.2	5.2	8.7
C-16	15.3	11.5	9.0	10.3	10.0	8.2	15.7
C-17	12.8	8.5	6.8	7.8	7.6	12.4	19.1
C-18	9.3	5.8	4.7	5.4	5.5	13.4	14.8
C-19	7.8	4.3	3.8	4.2	4.4	14.4	12.2
C-20	5.3	3.0	2.5	2.8	3.0	12.4	8.7
C-21	4.0	2.2	1.8	2.0	2.2	10.3	6.1
C-22	3.3	1.6	1.4	1.4	1.6	8.2	4.3
C-23	2.3	1.2	1.1	1.1	1.2	5.2	3.5
C-24	1.5	0.8	0.7	0.7	0.8	3.1	1.7
C-25	1.3	0.6	0.5	0.5	0.5	2.1	1.3
C-26	0.8	0.3	0.3	0.3	0.3	1.0	0.4
C-27	0.3	0.1	0.1	0.4	0.1		
C-28					0.1		
C-29							
C-30							
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 2 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12			11.3	12.2		0.9	
C-13	6.6	7.9	8.4	10.4	2.2	1.4	
C-14	11.1	10.5	6.2	10.0	4.0	3.3	
C-15	17.5	10.5	5.3	8.5	4.7	3.9	
C-16	18.0	7.9	4.6	7.5	4.3	3.9	
C-17	13.4	7.9	3.8	5.7	4.0	3.6	
C-18	10.1	5.3	3.8	5.7	3.7	3.3	7.7
C-19	8.0	5.3	5.3	6.0	3.1	3.1	12.8
C-20	5.3	5.3	6.0	5.1	2.8	2.8	13.8
C-21	3.4	7.9	6.5	4.5	2.8	1.7	12.8
C-22	2.1	7.9	6.5	4.0	2.2	2.1	10.2
C-23	1.3	10.5	6.7	3.8	1.9	2.0	10.2
C-24	0.7	5.3	6.2	2.8	1.6	1.7	7.7
C-25	0.3	5.3	5.8	2.8	1.6	1.7	7.7
C-26	0.1	2.6	4.8	2.2	1.6	1.6	5.1
C-27			3.6	1.9	2.8	2.3	5.1
C-28			2.4	1.5	5.3	4.4	2.6
C-29			1.7	1.5	9.9	8.2	2.6
C-30			0.7	1.1	14.0	11.3	1.2
C-31			0.2	1.1	15.5	13.6	0.6
C-32				0.9	12.1	12.4	
C-33				0.6		7.6	
C-34						3.4	
C-35							
C-36							
C-37							

TABLE 2 (continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV	XXXVI
C-12		5.5	13.4	6.6		8.7	8.1	8.4
C-13		6.3	9.2	6.9	0.9	7.5	7.6	8.8
C-14	3.5	8.0	9.2	7.5	5.5	7.8	8.7	8.8
C-15	7.0	8.0	8.4	8.4	8.2	7.5	8.4	8.4
C-16	8.1	7.0	7.7	8.4	9.1	6.0	6.7	7.8
C-17	7.6	5.9	6.3	7.3	8.2	5.7	5.0	7.1
C-18	8.1	5.7	6.3	8.1	8.2	5.6	6.0	6.5
C-19	8.9	6.3	5.6	7.5	9.1	6.5	5.0	6.5
C-20	8.6	5.5	6.3	6.6	8.2	5.8	6.6	6.2
C-21	8.1	5.5	5.6	6.2	7.3	5.8	6.6	5.5
C-22	7.3	5.5	4.9	5.6	7.3	5.8	6.7	5.2
C-23	6.8	5.7	4.2	5.1	6.4	5.6	6.7	4.5
C-24	5.9	5.5	3.5	4.3	5.5	5.2	5.0	3.9
C-25	5.4	5.1	3.5	3.6	4.5	4.7	4.9	3.6
C-26	4.1	4.2	2.1	2.8	3.6	4.2	2.9	2.9
C-27	3.2	3.4	1.4	2.4	2.7	3.0	1.6	2.3
C-28	2.4	2.3	1.1	1.5	1.8	2.1	1.2	1.6
C-29	1.9	1.9	0.7	1.3	1.8	1.6	0.9	1.0
C-30	1.4	1.3	0.4		0.9	0.8	0.6	0.6
C-31	1.1	0.8			0.9	0.4	0.4	0.3
C-32	0.5	0.4					0.1	
C-33								
C-34								
C-35								
C-36								
C-37								

TABLE 2 (continued)

Sample	XXXVII	XXXVIII
C-12		2.6
C-13	0.9	5.2
C-14	4.3	7.1
C-15	7.0	7.8
C-16	8.1	8.1
C-17	7.3	7.4
C-18	7.7	7.1
C-19	8.2	7.2
C-20	8.1	6.9
C-21	7.7	6.4
C-22	7.0	5.8
C-23	6.8	5.6
C-24	5.9	4.8
C-25	5.4	4.4
C-26	4.5	3.6
C-27	3.6	2.9
C-28	2.7	2.3
C-29	2.1	1.9
C-30	1.4	1.1
C-31	0.9	0.8
C-32	0.5	0.5
C-33		0.3
C-34		0.1
C-35		
C-36		
C-37		

TABLE 3

ADDITIONAL ANALYTICAL DATA FOR PLATFORM SAMPLES

Sample	Total n-Alkanes	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	18.6%	1.05	0.32	1.16
II	17.10%	0.87	0.24	0.75
III	1.50 ppm	0.76	0.23	0.82
IV	18.00%	1.12	0.41	0.88
V	10.80%	0.77	0.30	0.49
VI	58.00 ppb	0.80	0.30	1.01
VII	0	--	--	--
VIII	334.00 ppb	0.77	0.26	1.02
IX	17.00 ppb	1.00	0.33	0.58
X	136.00 ppb	0.82	0.31	1.06
XI	527.00 ppb	0.80	0.24	1.03
XII	260.00 ppb	0.95	0.41	1.00
XIII	16.00 ppb	--	--	1.28
XIV	567.00 ppb	1.00	0.49	1.06
XV	398.00 ppb	0.94	0.43	0.88
XVI	8.78 ppm	0.83	0.28	1.52
XVII	5.09 ppm	0.84	0.27	0.90
XVIII	4.69 ppm	0.81	0.27	1.29
XIX	6.25 ppm	0.88	0.28	0.95
XX	776.00 ppb	0.92	0.31	1.02
XXI	460.00 ppb	0.82	0.35	1.07
XXII	754.00 ppb	0.86	0.32	1.11
XXIII	293.00 ppb	1.00	1.00	1.23
XXIV	3.12 ppm	1.06	0.5	1.11
XXV	530.50 ppb	1.10	0.3	0.88
XXVI	9.02 ppm	0.85	0.25	0.94
XXVII	12.11 ppm	0.84	0.25	0.96
XXVIII	1.29 ppm	--	--	1.07
XXIX	3.70 ppm	1.00	0.30	1.00
XXX	2.01 ppm	1.10	0.52	0.96
XXXI	1.07 ppm	1.00	0.22	0.82
XXXII	5.14 ppm	1.09	0.40	0.95
XXXIII	935.00 ppb	1.00	0.28	1.00
XXXIV	3.48 ppm	0.98	0.54	0.93
XXXV	3.41 ppm	1.27	0.19	0.89
XXXVI	2.62 ppm	1.04	0.45	0.93
XXXVII	559.00 ppb	1.12	0.47	1.00
XXXVIII	1.57 ppm	1.09	0.50	0.99

TABLE 4

TABULATION OF WATER SAMPLES

Sample	Date	Location	Depth	Collection Method
I	06-05-76	Pfm. A	surface	diver
II	06-05-76	Pfm. A	mid-depth	diver
III	06-05-76	Pfm. A	bottom	diver
IV	06-05-76	Sta. 105	surface	bucket
V	06-06-76	Sta. 108	bottom	nansen
VI	06-11-76	Sta. 70	bottom	nansen
VII	06-11-76	Sta. 76	bottom	nansen
VIII	07-01-76	Sta. 9	surface	bucket
IX	07-01-76	Sta. 9	bottom	nansen
X	07-01-76	Jkt. 10	unknown	unknown
XI	07-02-76	Sta. 104	surface	bucket
XII	07-02-76	Sta. 104	bottom	nansen
XIII	08-31-76	Loc. 1	surface	bucket
XIV	08-31-76	Loc. 1	bottom	nansen
XV	08-31-76	Loc. 2	surface	bucket
XVI	08-31-76	Loc. 2	bottom	nansen
XVII	08-31-76	Loc. 3	surface	bucket
XVIII	08-31-76	Loc. 3	bottom	nansen
XIX	08-31-76	Loc. 4	surface	bucket
XX	08-31-76	Loc. 4	bottom	nansen
XXI	09-01-76	Loc. 5	surface	bucket
XXII	09-01-76	Loc. 5	bottom	nansen
XXIII	09-01-76	Loc. 6	surface	bucket
XXIV	09-01-76	Loc. 6	bottom	nansen
XXV	09-01-76	Loc. 7	surface	bucket
XXVI	09-01-76	Loc. 7	bottom	nansen
XXVII	09-01-76	Loc. 8	surface	bucket
XXVIII	09-01-76	Loc. 8	bottom	nansen
XXIX	09-01-76	Loc. 9	surface	bucket
XXX	09-01-76	Loc. 9	bottom	nansen
XXXI	09-01-76	Loc. 10	surface	bucket
XXXII	09-01-76	Loc. 10	bottom	nansen
XXXIII	09-01-76	Loc. 11	surface	bucket
XXXIV	09-01-76	Loc. 11	bottom	nansen
XXXV	09-23-76	H-1	surface	bucket
XXXVI	09-23-76	H-1	bottom	nansen
XXXVII	09-23-76	H-3	surface	bucket
XXXVIII	09-23-76	H-3	bottom	nansen
XXXIX	09-23-76	H-5	surface	bucket
XL	09-23-76	H-5	bottom	nansen
XLI	09-23-76	H-6	surface	bucket
XLII	09-23-76	H-6	bottom	nansen
XLIII	09-23-76	H-7	surface	bucket
XLIV	09-23-76	H-7	bottom	nansen
XLV	12-03-76	H-2	surface	nansen
XLVI	12-03-76	H-2	bottom	nansen
XLVII	12-03-76	H-4	surface	nansen
XLVIII	12-03-76	H-4	bottom	nansen

TABLE 4 (Continued)

Sample	Date	Location	Depth	Collection Method
XLIX	12-03-76	H-5	surface	nansen
L	12-03-76	H-5	bottom	nansen
LI	12-03-76	H-6	surface	nansen
LII	12-03-76	H-6	bottom	nansen
LIII	12-03-76	B	surface	nansen
LIV	12-03-76	B	bottom	nansen
LV	12-03-76	C	surface	nansen
LVI	12-03-76	C	bottom	nansen
LVII	12-03-76	F	surface	nansen
LVIII	12-03-76	G	surface	nansen
LIX	12-03-76	G	bottom	nansen
LX	12-17-76	1-1	surface	bottle
LXI	12-17-76	1-2	surface	bottle
LXII	12-17-76	1-3	surface	bottle
LXIII	12-17-76	1-3	surface	bottle
LXIV	12-17-76	1-5	surface	bottle
LXV	12-17-76	2-1	surface	bottle
LXVI	12-17-76	2-2	surface	bottle
LXVII	12-17-76	2-3	surface	bottle
LXVIII	12-17-76	2-4	surface	bottle
LXIX	02-15-77	X	surface	bucket
LXX	02-15-77	X	bottom	nansen
LXXI	02-16-77	P	surface	bucket
LXXII	02-16-77	P	bottom	nansen
LXXIII	02-17-77	Y	surface	bucket
LXXIV	02-17-77	Y	bottom	nansen
LXXV	03-02-77	Jkt. N	surface	bottle (diver)
LXXVI	03-02-77	Pfm. B	surface	bottle (diver)
LXXVII	10-05-77	PfmA-(center)	bottom	diver
LXXVIII	10-05-77	PfmA-E (8m.)	bottom	diver
LXXIX	10-05-77	PfmA-E (16.5m.)	bottom	diver
LXXX	10-05-77	PfmA-E (25m.)	bottom	diver
LXXXI	10-05-77	PfmA-E (33m.)	bottom	diver
LXXXII	10-28-77	PfmA-E (50m.)	bottom	diver
LXXXIII	10-28-77	PfmA-E (100m.)	bottom	diver
LXXXIV	10-28-77	PfmA-E (200m.)	bottom	diver
LXXXV	10-06-77	PfmA-W (8m.)	bottom	diver
LXXXVI	10-06-77	PfmA-W (25m.)	bottom	diver
LXXXVII	10-06-77	PfmA-W (33m.)	bottom	diver
LXXXVIII	10-28-77	PfmA-W (50m.)	bottom	diver
LXXXIX	10-28-77	PfmA-W (100m.)	bottom	diver
XC	10-28-77	PfmA-W (200m.)	bottom	diver
XCI	10-06-77	JKtB-(center)	bottom	diver
XCII	10-06-77	JKtB-E (8m.)	bottom	diver
XCIII	10-06-77	JKtB-E (16.5m.)	bottom	diver
XCIV	10-06-77	JKtB-E (25m.)	bottom	diver
XCV	10-06-77	JKtB-E (33m.)	bottom	diver
XCVI	10-28-77	JKtB-E (50m.)	bottom	diver
XCVII	10-28-77	JKtB-E (100m.)	bottom	diver
XCVIII	10-28-77	JKtB-E (200m.)	bottom	diver

TABLE 4 (Continued)

Sample	Date	Location	Depth	Collection Method
XCIX	10-07-77	JKtB-W (8m.)	bottom	diver
C	10-07-77	JKtB-W (16.5m.)	bottom	diver
CI	10-07-77	JKtB-W (25m.)	bottom	diver
CII	10-07-77	JKtB-W (33m.)	bottom	diver
CIII	10-28-77	JKtB-W (50m.)	bottom	diver
CIV	10-28-77	JKtB-W (100m.)	bottom	diver
CV	10-28-77	JKtB-W (200m.)	bottom	diver
CVI	02-05-78	PfmB-2	surface	bottle
CVII	02-05-78	PfmB-3	surface	bottle
CVIII	02-05-78	PfmB-4	surface	bottle
CIX	2-5-78	PfmB-5	surface	bottle
CX	2-5-78	PfmB-6	surface	bottle
CXI	2-5-78	PfmB-7	surface	bottle
CXII	2-5-78	PfmB-9	surface	bottle
CXIII	2-5-78	PfmB-10	surface	bottle
CXIV	2-5-78	PfmB-11	surface	bottle
CXV	2-5-78	PfmB-12	surface	bottle
CXVI	2-5-78	PfmB-13	surface	bottle
CXVII	2-5-78	PfmB-14	surface	bottle
CXVIII	2-5-78	PfmB-15	surface	bottle
CXIX	2-5-78	PfmB-16	surface	bottle
CXX	2-5-78	PfmB-17	surface	bottle
CXXI	2-5-78	PfmB-18	surface	bottle
CXXII	2-5-78	PfmB-20	surface	bottle
CXXIII	2-12-78	PfmB-21	surface	bottle
CXXIV	2-12-78	PfmB-22	surface	bottle
CXXV	2-12-78	PfmB-23	surface	bottle
CXXVI	2-12-78	PfmB-24	surface	bottle
CXXVII	2-12-78	PfmB-25	surface	bottle
CXXVIII	2-12-78	PfmB-26	surface	bottle
CXXIX	2-12-78	PfmB-27	surface	bottle
CXXX	2-12-78	PfmB-28	surface	bottle
CXXXI	2-12-78	PfmB-29	surface	bottle
CXXXII	2-12-78	PfmB-30	surface	bottle
CXXXIII	2-12-78	PfmB-31	surface	bottle
CXXXIV	2-12-78	PfmB-32	surface	bottle
CXXXV	2-12-78	PfmB-33	surface	bottle
CXXXVI	2-12-78	PfmB-34	surface	bottle
CXXXVII	2-12-78	PfmB-35	surface	bottle
CXXXVIII	2-12-78	PfmB-36	surface	bottle
CXXXIX	2-12-78	PfmB-37	surface	bottle
CXL	2-12-78	PfmB-38	surface	bottle
CXLI	2-12-78	PfmB-39	surface	bottle
CXLII	2-12-78	PfmB-40	surface	bottle

TABLE 5.

DISTRIBUTION OF n-ALKANES IN WATER SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12	18.6	0.6	2.8	1.1			
C-13	13.5	0.3	5.7	0.5			
C-14	11.8	2.0	2.6	0.5			
C-15	11.0	2.3	3.0	1.1			
C-16	11.0	2.9	4.2	2.2	2.7		
C-17	8.4	2.9	3.2	7.6	2.7		
C-18	7.6	2.2	3.4	13.0			
C-19	4.2	1.7	1.9	17.3			
C-20	3.4	0.7	1.9	14.1	2.7		
C-21	2.5	0.9	1.1	7.6	2.7		
C-22		1.5	1.1	3.2	5.4		
C-23			1.1	1.1	2.7		
C-24	1.3	0.9	1.3	1.1	5.4		3.6
C-25			4.0		32.4	21.1	10.7
C-26			1.9	3.2	5.4	4.8	3.6
C-27		1.5	2.6		5.4	7.7	10.7
C-28		9.3	3.4		10.8	7.7	10.7
C-29		4.1	3.8	1.1	2.7	2.4	3.6
C-30	2.5	10.5	6.6	4.3	2.7	2.4	3.6
C-31		5.8	7.5	5.4	2.7	2.4	3.6
C-32	1.7	13.7	14.2	3.2	2.7	21.4	28.6
C-33	0.8	9.9	7.0	3.2	5.4	15.3	21.4
C-34	0.4	8.1	5.7	2.2	2.7	15.3	
C-35	0.4	5.8	4.0	1.6	2.7		
C-36	0.8	4.7	2.6	2.2			
C-37							

TABLE 5 (Continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12							
C-13							
C-14	3.4						
C-15	7.9	0.7	2.4	0.9		0.3	0.2
C-16	9.9	0.7	2.4	3.6		2.1	0.4
C-17	12.8	0.7	16.1	8.1		18.4	0.9
C-18	6.4	0.7	2.4	5.4		16.4	0.9
C-19	3.4	0.7	2.4	6.3		23.2	1.7
C-20	3.4	0.4	0.8	2.7		17.8	1.7
C-21	1.5	0.4	1.6	2.7		10.2	0.9
C-22	1.5	0.4	2.4	3.6		5.4	0.4
C-23	1.5	0.4	2.4	5.4		2.3	
C-24	1.5	0.4	2.4	3.6		1.1	0.4
C-25	3.4	0.7	6.5	11.7	19.0	0.8	0.6
C-26	2.0	1.4	4.0	3.6		0.6	0.9
C-27	6.4	2.8	4.0	4.5	9.5	0.1	1.7
C-28	11.3	7.0	7.3	9.0	19.0	0.3	3.9
C-29	2.0	9.8	4.0	3.6	9.5		4.8
C-30	4.9	11.2	5.6	3.6	9.5		8.7
C-31	4.9	15.4	9.7	6.3	9.5	0.2	15.6
C-32	4.9	14.0	7.3	5.4	9.5	0.1	16.5
C-33	3.4	11.2	6.5	3.6	9.5	0.1	18.6
C-34	2.0	7.0	4.0	3.6	4.8	0.2	11.7
C-35	1.5	4.9	3.2	2.7		0.1	9.5
C-36		7.0	2.4				
C-37		2.1					

TABLE 5 (Continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12							
C-13							
C-14							
C-15				0.8	1.1	0.7	2.2
C-16	0.5	1.3		1.2	3.2	0.7	6.6
C-17	3.3	1.3	3.7	1.4	8.9	1.4	13.2
C-18	9.9	3.9	10.6	2.3	15.6	1.8	13.7
C-19	20.3	7.7	21.2	2.3	22.0	2.1	15.4
C-20	21.7	7.2	24.3	2.3	20.6	2.1	13.7
C-21	16.5	3.9	16.9	1.2	12.8	1.1	8.8
C-22	9.4	2.6	10.6	0.6	7.1	0.7	4.4
C-23	5.2	1.3	5.3	0.6	3.2	0.4	2.2
C-24	2.8	0.7	2.6	0.6	1.8	0.4	2.2
C-25	2.8	3.9	1.1	0.6	1.8	1.1	2.2
C-26	0.9	1.3	0.5	0.6	0.7	0.7	2.2
C-27	0.9	1.3	0.5	0.8	0.4	1.4	2.2
C-28	1.4	3.3	0.5	2.9	0.2	1.8	2.2
C-29	1.9	3.9	0.5	4.6	0.2	4.3	2.2
C-30	0.5	5.9	0.5	7.8	0.2	7.8	1.1
C-31	0.5	10.5	0.5	13.9	0.2	13.8	1.1
C-32	0.5	10.5	0.5	13.9		15.6	1.1
C-33	0.5	11.8		16.2		16.7	1.1
C-34	0.5	7.8		9.8		10.3	1.1
C-35		5.2		8.1		7.9	1.1
C-36		3.3		7.0		4.6	1.1
C-37		2.0		2.9			

TABLE 5 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12							
C-13							
C-14							
C-15			4.3		7.7		
C-16	0.6		8.7		15.4		
C-17	0.6	4.2	4.3	15.2	7.7	7.0	50.0
C-18	0.6	10.6	8.7	14.1	7.7	15.8	16.6
C-19	0.6	19.0	8.7	21.7	7.7	22.8	16.6
C-20	0.8	19.0	8.7	19.6	7.7	19.3	
C-21	0.6	14.1	4.3	11.9	3.8	12.3	
C-22	0.3	7.7	4.3	6.5	3.8	7.0	16.6
C-23	0.3	4.2	2.2	3.3	3.8	3.5	
C-24	0.6	2.1	4.3	2.2	3.8	1.8	
C-25	0.6	2.8	8.7	1.1	3.8	1.8	
C-26	1.1	1.4	4.3	1.1	3.8	1.8	
C-27	1.1	1.4	4.3	1.1	7.7	1.8	
C-28	3.4	2.8	4.3	1.1	3.8	1.8	
C-29	5.1	0.7	4.3	1.1	3.8	1.8	
C-30	8.5	0.7	4.3			0.9	
C-31	15.3	0.7	4.3		3.8	0.9	
C-32	15.3	0.7	2.2		3.8		
C-33	17.6	1.4	2.2				
C-34	10.8	1.4	2.2				
C-35	7.9	1.4					
C-36	5.1	2.1					
C-37	3.4	1.4					

TABLE 5 (Continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV
C-12							
C-13							
C-14					2.2		
C-15	0.8	3.0	1.7	5.4	5.0	1.5	
C-16	2.4	9.1	3.4	5.4	8.6	1.5	16.7
C-17	6.3	6.1	6.8	8.1	11.5	1.5	16.7
C-18	12.6	6.1	10.2	5.4	11.8		
C-19	22.0	12.1	14.7	5.4	13.6	2.4	
C-20	20.5	15.2	13.6	5.4	11.5	2.4	
C-21	12.6	6.1	7.9	2.7	6.8	1.5	
C-22	6.3	3.0	5.1	5.4	5.0	3.0	
C-23	3.1	3.0	2.8	5.4	4.3	3.0	
C-24	1.6	3.0	2.3	2.7	3.2	3.0	
C-25	2.4	3.0	3.4		3.6	6.5	
C-26	0.8	3.0	1.7	2.7	2.5	3.6	16.7
C-27	0.8	3.0	2.3	8.1	1.8	5.9	16.7
C-28		3.0	3.4	5.4	2.9	8.9	16.7
C-29		3.0	2.8	2.7	2.2	5.9	16.7
C-30		3.0	2.8	5.4	1.8	6.5	
C-31		3.0	4.0	8.1	2.5	11.8	
C-32	7.9	3.0	4.0	5.4	2.2	8.9	
C-33			2.8	5.4	1.8	8.9	
C-34			1.7	2.7	0.7	5.9	
C-35			1.7		0.7	3.0	
C-36			1.1		0.4	4.1	
C-37							

TABLE 5 (Continued)

Sample	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
C-12							
C-13							
C-14							
C-15		4.8			14.5		
C-16	8.3	9.5		12.5	28.9	3.4	44.4
C-17	16.7	19.0		25.0	14.5	21.3	44.4
C-18	8.3	9.5		12.5	6.9	11.4	
C-19		4.8		10.0		14.2	
C-20		9.5					
C-21							
C-22		4.8				7.1	
C-23							
C-24	8.3	4.8			6.9		
C-25		9.5	50.0	10.0	6.9		
C-26	8.3	4.8		10.0	6.9	7.1	
C-27		4.8		10.0			
C-28		8.3	14.3	50.0	10.0	7.1	11.1
C-29	16.7						
C-30	16.7					28.4	
C-31	8.3						
C-32	8.3						
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	XLIII	XLIV	XLV	XLVI	XLVII	XLVIII	XLIX
C-12				0			
C-13							
C-14						2.6	
C-15	15.3	8.3				5.1	
C-16					9.1	5.1	
C-17	24.5	8.3			18.2	10.3	14.2
C-18	7.4	4.2			36.4	6.2	14.2
C-19		4.2			36.4	5.1	14.2
C-20			8.7			2.6	
C-21		4.2	4.3			5.1	7.3
C-22		8.3	8.7			6.2	
C-23		8.3	8.7			6.2	
C-24	7.4	8.3	8.7			5.1	
C-25	15.3	16.7	8.7			5.1	14.2
C-26	7.4	8.3	8.7			5.1	14.2
C-27	7.4	8.3	8.7			5.1	
C-28	15.3	8.3	8.7			6.2	14.2
C-29		4.2	8.7			6.2	7.3
C-30			8.7			2.6	
C-31			8.7			2.6	
C-32						2.6	
C-33						2.6	
C-34						2.6	
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	L	LI	LII	LII	LIV	LV	LVI
C-12		0	0	0	0		0
C-13							
C-14							
C-15							
C-16							
C-17	5.9						
C-18	2.9						
C-19	11.8						
C-20							
C-21	11.8						
C-22	11.8					25.0	
C-23	11.8						
C-24						25.0	
C-25						25.0	
C-26	5.9						
C-27	5.9						
C-28						25.0	
C-29	5.9						
C-30	5.9						
C-31	5.9						
C-32	2.9						
C-33							
C-34	5.9						
C-35	5.9						
C-36							
C-37							

TABLE 5 (Continued)

Sample	LVII	LVIII	LIX	LX	LXI	LXII	LXIII
C-12			0				
C-13							
C-14							0.2
C-15				4.1	4.8		2.2
C-16	4.6	0.9		6.1	4.8	3.7	3.7
C-17	13.8	3.7		16.3	9.5	7.4	6.5
C-18	4.6	8.4		8.2	4.8	7.4	6.5
C-19	18.3	14.9		8.2	4.8	7.4	6.5
C-20	18.3	8.4		8.2	4.8	7.4	4.3
C-21	4.6	17.7		4.1	4.8	11.1	2.2
C-22		13.0		4.1		3.7	15.2
C-23		16.7		2.0	4.8		6.5
C-24		3.7		2.0	4.8		6.5
C-25	9.2			6.1	9.5	7.4	8.7
C-26	4.6	1.9		4.1	4.8	7.4	6.5
C-27	9.2	1.9		6.1	4.8	11.1	5.4
C-28	9.2			8.2	9.5	14.8	8.7
C-29	3.7	0.9		2.0	4.8	7.4	6.5
C-30		0.5		4.1	4.8	3.7	
C-31				2.0	4.8		2.2
C-32		0.9		4.1	4.8		
C-33		0.9			4.8		0.2
C-34		1.9					0.7
C-35		1.9					0.7
C-36		1.9					
C-37							

TABLE 5 (Continued)

Sample	LXIV	LXV	LXVI	LXVII	LXVIII	LXIX	LXX
C-12							
C-13							
C-14							
C-15	13.3		3.8	2.4	9.1		
C-16	13.3	2.9	15.4	5.9	9.1		
C-17	26.7	8.8	30.8	11.8	18.2	44.4	100.0
C-18	13.3	8.8	3.8	17.6	9.1	55.6	
C-19		5.9	3.8	17.6			
C-20	13.3	5.9		11.8			
C-21		5.9		5.9			
C-22	6.7	2.9	3.8	2.4			
C-23			3.8	2.4			
C-24		5.9					
C-25	6.7	11.8	15.4	14.1			
C-26		8.8	3.8		9.1		
C-27		8.8	7.7		18.2		
C-28	6.7	17.6	7.7	5.9	18.2		
C-29		5.9		2.4	9.1		
C-30							
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	LXXI	LXXII	LXXIII	LXXIV	LXXV	LXXVI
C-12	0					
C-13						
C-14						
C-15						
C-16						20.0
C-17		100.0	100.0	44.4	15.4	40.0
C-18				55.6	7.7	20.0
C-19					15.4	
C-20					15.4	20.0
C-21					15.4	
C-22					15.4	
C-23					7.7	
C-24					7.7	
C-25						
C-26						
C-27						
C-28						
C-29						
C-30						
C-31						
C-32						
C-33						
C-34						
C-35						
C-36						
C-37						

TABLE 5 (Continued)

Sample	LXXVII	LXXVIII	LXXIX	LXXX	LXXXI	LXXXII	LXXXIII
C-12							
C-13							
C-14							
C-15							
C-16							
C-17			2.0		3.8		10.1
C-18			2.0		7.6		26.8
C-19		2.8	2.0		5.3		31.5
C-20							12.8
C-21		5.6	1.3		3.8		4.7
C-22		8.3	2.0		3.8	11.1	2.0
C-23	6.9	8.3	2.7	6.7	3.8	11.1	1.3
C-24	13.8	11.1	3.3	13.3	7.6	11.1	1.3
C-25	13.8	11.1	5.3	13.3	11.4	11.1	2.0
C-26	13.8	11.1	7.3	13.3	11.4	11.1	2.0
C-27	13.8	13.9	11.3	13.3	11.4	11.1	2.0
C-28	13.8	11.1	14.7	13.3	15.2	11.1	2.0
C-29	10.3	8.3	16.7	13.3	7.6	11.1	0.7
C-30	6.9	5.6	12.7	13.3	3.8	11.1	0.7
C-31	6.9	2.8	9.3		3.8		
C-32			4.7				
C-33			2.0				
C-34			0.7				
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	LXXXIV	LXXXV	LXXXVI	LXXXVII	LXXXVIII	LXXXIX	XC
C-12							
C-13							
C-14							
C-15							
C-16							
C-17				5.9		7.8	
C-18				5.9		24.3	
C-19		19.5		5.9		27.8	
C-20						12.2	
C-21		19.5	2.6	2.9		7.8	12.5
C-22		6.1	2.6	5.9	6.7	2.6	
C-23		6.1	5.1	5.9	13.3	2.6	12.5
C-24		6.1	5.1	8.8	13.3	1.7	12.5
C-25		6.1	10.3	8.8	13.3	2.6	12.5
C-26	25.0	12.2	10.3	8.8	13.3	2.6	12.5
C-27	25.0	6.1	15.4	11.8	13.3	2.6	25.0
C-28	25.0	6.1	15.4	11.8	13.3	2.6	12.5
C-29	25.0	6.1	12.8	11.8	13.3	1.7	12.5
C-30		6.1	10.3	5.9		0.9	
C-31			5.1				
C-32			5.1				
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	XCI	XCII	XCIII	XCIV	XCV	XCVI	XCVII
C-12							
C-13							
C-14							
C-15	7.0				0.7		
C-16	4.7				1.4		
C-17	4.7				7.2		5.7
C-18	4.7	7.9			26.0		5.7
C-19	2.3	13.2			26.0		5.7
C-20		18.4			15.4		
C-21	2.3	15.8			8.7		5.7
C-22	4.7	5.3		8.3	3.8	6.7	5.7
C-23	4.7	3.9		16.7	2.4	6.7	5.7
C-24	7.0	3.9	7.7	16.7	1.7	13.3	8.0
C-25	7.0	5.3	7.7	8.3	1.7	13.3	11.5
C-26	9.3	5.3	15.4	8.3	1.7	13.3	11.5
C-27	9.3	5.3	15.4	8.3	1.2	26.7	11.5
C-28	9.3	5.3	23.1	16.7	1.0	13.3	17.2
C-29	9.3	5.3	15.4	8.3	0.7	6.7	5.7
C-30	4.7	2.6	7.7	8.3	0.2		
C-31	4.7	1.3	7.7		0.2		
C-32	4.7	1.3					
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	XCVIII	XCIX	C	CI	CII	CIII	CIV
C-12							0
C-13							
C-14							
C-15							
C-16							
C-17		6.4					
C-18		24.4		17.0	13.3		
C-19		25.9		30.2	30.7		
C-20		20.0		18.9	20.0		
C-21		9.3	6.7	3.8	8.0		
C-22		3.4	6.7	3.8	4.0		
C-23	10	1.0	6.7	1.9	1.8		
C-24	10	1.5	6.7	3.8	1.8		
C-25	20	2.0	6.7	3.8	4.0	12.5	
C-26	20	2.4	13.3	3.8	4.0	12.5	
C-27	20	1.5	13.3	3.8	4.0	25.0	
C-28	20	1.0	13.3	5.7	4.0	37.5	
C-29		0.7	13.3	3.8	1.8	12.5	
C-30		0.2	6.7		1.3		
C-31		0.2	6.7		1.3		
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	CV	CVI	CVII	CVIII	CIX	CX	CXI
C-12		0	0	0		0	0
C-13							
C-14							
C-15							
C-16							
C-17							
C-18							
C-19							
C-20							
C-21							
C-22							
C-23							
C-24					16.7		
C-25					16.7		
C-26					16.7		
C-27	33.3						
C-28	33.3				16.7		
C-29	33.3				16.7		
C-30					16.7		
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	CXII	CXIII	CXIV	CXV	CXVI	CXVII	CXVIII
C-12	0		0				
C-13							
C-14							
C-15							
C-16							5
C-17				19.7			40
C-18				29.5		25.7	20
C-19				19.7		25.7	5
C-20				16.4		10.3	5
C-21				6.6		5.1	5
C-22				1.6		5.1	5
C-23				3.3		2.5	2.5
C-24				1.6		5.1	2.5
C-25				1.6		5.1	2.5
C-26						5.1	2.5
C-27		20			20	5.1	
C-28					20	2.5	5
C-29		20			20	2.5	
C-30		20			20		
C-31		40			20		
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 5 (Continued)

Sample	CXIX	CXX	CXXI	CXXII	CXXIII	CXXIV	CXXV	CXXVI
C-12	0			0				
C-13								
C-14					2.4		10.4	
C-15					2.0		7.4	
C-16					2.0	2.0	7.4	15.6
C-17		25.6			3.1	6.1	11.1	13.0
C-18		20.5			5.2	13.5	20.7	10.4
C-19		20.5			5.6	17.8	20.7	10.4
C-20		5.1			4.3	15.1	13.3	2.6
C-21		5.1			3.8	11.8	8.9	7.8
C-22		2.6			6.6	8.2		6.5
C-23		5.1			7.3	6.3		5.2
C-24		2.6			9.0	4.9		5.2
C-25		2.6	12.5		10.1	4.1		5.2
C-26		2.6	12.5		10.1	3.1		5.2
C-27		5.1	12.5		8.3	2.5		5.2
C-28		2.6	12.5		6.9	1.6		5.2
C-29			12.5		5.6	1.6		2.6
C-30			25		3.8	1.6		
C-31			12.5		2.4	0.8		
C-32					1.0			
C-33					0.4			
C-34								
C-35								
C-36								
C-37								

TABLE 5 (Continued)

Sample	CXXVII	CXXVIII	CXXIX	CXXX	CXXXI	CXXXII	CXXXIII	CXXXIV	CXXXV
C-12						0			
C-13		11.8	15.8		26.7				
C-14		8.6	11.8		6.7				
C-15		7.2	9.5		13.3				
C-16		6.6	7.9		6.7		2.4		
C-17	3.6	7.9	7.9	13.3	13.3		7.7	7.1	11.4
C-18	3.6	11.2	6.3	26.7	6.7		22.6	7.1	11.4
C-19	4.6	11.2	6.3	26.7	6.7		24.1	7.1	11.4
C-20	3.6	7.2	1.6	10.0	--		15.4	7.1	--
C-21	7.3	5.9	3.2	13.3	6.7		9.6	7.1	7.1
C-22	8.8	4.6	3.2	6.7	6.7		4.3	7.1	7.1
C-23	7.3	3.3	3.2		6.7		2.4	7.1	7.1
C-24	7.3	2.6	3.2				2.4	7.1	7.1
C-25	6.4	2.6	3.2				2.0	7.1	7.1
C-26	5.6	2.0	3.2				2.0	7.1	7.1
C-27	5.6	2.0	4.0				1.4	7.1	7.1
C-28	5.6	2.0	4.0				--	7.1	15.0
C-29	6.4	2.0	4.0				2.9	7.1	
C-30	10.1	1.3	1.6					7.1	
C-31	9.1								
C-32	5.6								
C-33									
C-34									
C-35									
C-36									
C-37									

TABLE 5 (Continued)

Sample	CXXXVI	CXXXVII	CXXXVIII	CXXXIX	CXL	CXLI	CXLII
						0	
C-12							
C-13							3.6
C-14							--
C-15							--
C-16	9.1						--
C-17	7.4						3.6
C-18	21.3			11.1			--
C-19	24.3	25.0		7.4			--
C-20	24.1	--	1.1	11.1			--
C-21	16.7	25.0	2.8	11.1	2.3		3.6
C-22	11.1	25.0	5.6	11.1	5.6		7.1
C-23	5.6	25.0	8.3	11.1	9.2		10.7
C-24	3.7		12.2	11.1	11.7		12.5
C-25	1.9		12.2	7.4	13.0		12.5
C-26	1.9		12.2	7.4	13.0		10.7
C-27	1.9		13.3	3.7	11.9		10.7
C-28	1.9		--		10.3		8.9
C-29			12.2		8.4		7.1
C-30			7.8		6.5		5.4
C-31			6.7		4.2		3.6
C-32			5.6		2.3		
C-33					0.8		
C-34							
C-35							
C-36							
C-37							

TABLE 6

ADDITIONAL ANALYTICAL DATA FOR WATER SAMPLES

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	11.9	0.80	0.22	0.70
II	3.4	0.80	0.27	0.58
III	5.3	0.82	0.33	0.91
IV	4.5	0.70	0.50	1.03
V	1.9	--	--	1.47
VI	1.1	--	--	0.94
VII	0.7	--	--	1.00
VIII	2.0	0.65	0.50	0.95
IX	14.3	1.00	0.50	0.95
X	24.8	--	--	1.43
XI	1.1	0.90	0.50	1.20
XII	10.5	--	--	1.33
XIII	35.3	0.69	0.52	1.26
XIV	23.1	0.50	0.75	0.99
XV	21.2	0.71	0.48	1.09
XVI	7.7	1.00	0.50	1.10
XVII	9.5	0.71	0.50	0.99
XVIII	8.6	0.70	0.42	1.10
XIX	14.1	0.72	0.46	1.01
XX	14.1	0.85	0.40	1.09
XXI	4.6	0.67	0.50	1.07
XXII	17.7	0.50	0.50	1.05
XXIII	7.1	0.67	0.47	1.03
XXIV	1.2	1.00	0.50	0.92
XXV	9.2	0.71	0.46	1.22
XXVI	1.3	1.00	0.50	1.00
XXVII	5.7	1.00	0.44	1.05
XXVIII	3.0	1.20	1.00	1.00
XXIX	6.4	0.63	0.44	0.90
XXX	3.3	1.00	1.00	1.06
XXXI	17.7	0.67	0.50	1.03
XXXII	3.7	0.67	0.50	1.18
XXXIII	29.7	0.79	0.51	1.06
XXXIV	1.7	1.00	--	1.07
XXXV	0.15	--	--	1.00
XXXVI	0.60	--	--	0.72
XXXVII	0.53	1.00	--	0.75
XXXVIII	0.05	--	--	1.00
XXXIX	0.20	1.50	1.00	1.22
XL	0.17	1.00	--	0.72
XLI	0.35	1.00	1.00	0.55
XLII	0.23	--	--	0.80
XLIII	0.16	1.00	0.83	0.89
XLIV	0.60	1.00	1.00	1.19
XLV	4.6	--	--	0.92
XLVI	0	--	--	--
XLVII	0.6	1.00	2.00	1.20

TABLE 6 (Continued)

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XLVIII	1.0	1.00	0.83	1.13
XLVIX	2.5	0	0	1.35
L	0.9	1.00	2.00	1.83
LI	0	--	--	--
LII	0	--	--	--
LIII	0	--	--	--
LIV	0	--	--	--
LV	0.4	--	--	0.33
LVI	0	--	--	--
LVII	0.5	1.33	2.00	1.42
LVIII	10.8	1.00	0.67	1.41
LIX	0	--	--	--
LX	2.5	0.75	0.50	1.04
LXI	2.1	0.75	1.00	1.31
LXII	2.7	1.00	0.50	.08
LXIII	4.6	0.77	0.43	.91
LXIV	0.8	1.00	0	0.88
LXV	34	0	0	0.89
LXVI	2.4	0.75	1.00	1.89
LXVII	0.9	1.50	0.67	1.29
LXVIII	3.3	1.00	1.50	1.20
LXIX	1.8	--	--	0.80
LXX	0.5	--	--	--
LXXI	0	--	--	--
LXXII	1.2	--	--	--
LXXIII	0.7	--	--	--
LXXIV	0.9	--	0.40	0.30
LXXV	0.3	0	0	1.60
LXXVI	0.1	0	2.00	0.66
LXXVII	1.45	--	--	1.07
LXXVIII	7.2	--	--	1.12
LXXIX	15.0	0.3	0.3	1.11
LXXX	1.5	--	--	0.88
LXXXI	1.32	0.6	0.5	1.03
LXXXII	0.9	--	--	0.80
LXXXIII	14.9	0.47	0.32	1.10
LXXXIV	0.8	--	--	1.0
LXXXV	8.2	--	--	1.73
LXXXVI	7.8	--	--	1.05
LXXXVII	1.7	--	--	1.25
LXXXVIII	1.5	--	--	1.15
LXXXIX	11.0	0.44	0.32	1.04
XC	1.6	--	--	1.67
XCI	2.15	1.0	--	1.05
XCII	7.6	--	0.33	1.0
XCIII	2.6	--	--	0.86
XCIV	1.2	--	--	0.72
XCV	20.8	0.3	0.2	0.95
XCVI	0.75	--	--	1.15

TABLE 6 (Continued)

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XCVII	0.87	--	--	1.08
XCVIII	1.0	--	--	1.0
XCIX	40.9	0.31	0.2	0.88
C	3.0	--	--	1.14
CI	5.3	--	0.33	0.89
CII	22.5	--	0.30	1.08
CIII	0.8	--	--	1.0
CIV	0	--	--	--
CV	0.6	--	--	2.0
CVI	0	--	--	--
CVII	0	--	--	--
CVIII	0	--	--	--
CIX	3.0	--	--	0.5
CX	0	--	--	--
CXI	0	--	--	--
CXII	0	--	--	4.0
CXIII	5.6	--	--	--
CXIV	0	--	--	--
CXV	79.3	1.33	1.22	1.03
CXVI	2.5	--	--	1.50
CXVII	48.6	--	--	0.85
CXVIII	48	1.25	1.75	1.22
CXIX	0	--	--	--
CXX	46.8	--	--	1.79
CXXI	2.4	--	--	1.0
CXXII	0	--	--	--
CXXIII	28.9	0.56	0.2	0.94
CXXIV	24.5	0.74	0.24	0.97
CXXV	6.75	0.6	0.29	0.87
CXXVI	3.85	0.6	0.25	0.97
CXXVII	7.2	0.5	--	1.01
CXXVIII	7.6	0.59	0.24	1.17
CXXIX	7.3	0.69	0.3	1.24
CXXX	1.5	0.5	0.25	1.23
CXXXI	1.5	--	--	2.25
CXXXII	0	--	--	--
CXXXIII	7.0	--	3.95	0.96
CXXXIV	1.7	--	--	1.0
CXXXV	1.4	--	--	--
CXXXVI	5.4	0.63	0.26	1.02
CXXXVII	0.4	--	--	--
CXXXVIII	9.0	--	--	1.43
CXXXIX	2.7	0.33	--	1.17
CXL	27.2	--	--	0.99
CXLI	0	--	--	--
CXLII	2.8	--	--	1.08

TABLE 7

TABULATION OF BARNACLE SAMPLES

Sample	Date	Location	Depth	Material
I	9-25-76	Pfm A	surface	flesh
II	9-25-76	Pfm A	surface	shell
III	9-25-76	Pfm A	10 m	flesh
IV	9-25-76	Pfm A	10 m	shell
V	9-25-76	Pfm B	surface	flesh
VI	9-25-76	Pfm B	surface	shell
VII	9-25-76	Pfm B	10 m	flesh
VIII	9-25-76	Pfm B	10 m	shell
IX	9-25-76	Jkt I	surface	flesh
X	9-25-76	Jkt I	surface	shell
XI	9-25-76	Jkt I	surface	flesh
XII	9-25-76	Jkt I	10 m	shell
XIII	9-25-76	Jkt A	surface	flesh
XIV	9-25-76	Jkt A	surface	shell
XV	9-25-76	Jkt A	10 m	flesh
XVI	9-25-76	Jkt A	10 m	shell
XVII	9-25-76	Jkt K	surface	flesh
XVIII	9-25-76	Jkt K	surface	shell
XIX	9-25-76	Jkt K	10 m	flesh
XX	9-25-76	Jkt K	10 m	shell
XXI	9-25-76	Jkt H	surface	flesh
XXII	9-25-76	Jkt H	surface	shell
XXIII	9-25-76	Jkt H	10 m	flesh
XXIV	9-25-76	Jkt H	10 m	shell
XXV	9-25-76	Jkt C	surface	flesh
XXVI	9-25-76	Jkt C	surface	shell
XXVII	9-25-76	Jkt C	10 m	flesh
XXVIII	9-25-76	Jkt C	10 m	shell
XXIX	9-25-76	Jkt F	surface	flesh
XXX	9-25-76	Jkt F	surface	shell
XXXI	9-25-76	Jkt F	10 m	flesh
XXXII	9-25-76	Jkt F	10 m	shell
XXXIII	9-25-76	Jkt G	surface	flesh
XXXIV	9-25-76	Jkt G	surface	shell
XXV	9-25-76	Jkt G	10 m	flesh
XXVI	9-25-76	Jkt G	10 m	shell
XXXVII	1-21-77	Pfm A	surface	flesh
XXXVIII	1-21-77	Pfm A	surface	shell
XXXIX	1-21-77	Pfm A	13 m	flesh
XL	1-21-77	Pfm A	13 m	shell
XLI	1-22-77	Jkt 0	surface	flesh
XLII	1-22-77	Jkt 0	surface	shell
XLIII	1-22-77	Jkt 0	13 m	flesh
XLIV	1-22-77	Jkt 0	13 m	shell
XLV	3-2-77	Jkt I	12 m	flesh
XLVI	3-2-77	Jkt I	12 m	shell
XLVII	3-2-77	Jkt K	11 m	flesh
XLVIII	3-2-77	Jkt K	11 m	shell

TABLE 7 (Continued)

Sample	Date	Location	Depth	Material
XLIX	3-2-77	Jkt N	7.5 m	flesh
L	3-2-77	Jkt N	7.5 m	shell
LI	3-2-77	Jkt N	15 m	flesh
LII	3-2-77	Jkt N	15 m	shell
LIII	3-2-77	Jkt M	15 m	flesh
LIV	3-2-77	Jkt M	15 m	shell
LV	3-2-77	Jkt M	7.5 m	flesh
LVI	3-2-77	Jkt M	7.5 m	shell
LVII	7-28-77	PfmA	surface	flesh
LVIII	7-28-77	PfmA	10m	flesh
LIX	7-28-77	PfmA	10m	shell
LX	7-29-77	JKtB	surface	flesh
LXI	7-29-77	JKtB	surface	shell
LXII	7-29-77	JKtB	16m	flesh
LXIII	7-29-77	JKtB	16m	shell
LXIV	8-12-77	PfmA discharge	surface	flesh
LXV	8-12-77	PfmA discharge	surface	shell
LXVI	8-12-77	PfmA discharge	20m	flesh
LXVII	8-12-77	PfmA discharge	20m	shell
LXVIII	8-12-77	PfmA nondischarge	surface	flesh
LXIX	8-12-77	PfmA nondischarge	surface	shell
LXX	8-12-77	PfmA nondischarge	20m	flesh
LXXI	8-12-77	PfmA nondischarge	20m	shell
LXXII	8-12-77	QtrA discharge	surface	flesh
LXXIII	8-12-77	QtrA discharge	surface	shell
LXXIV	8-12-77	QtrA discharge	20m	flesh
LXXV	8-12-77	QtrA discharge	20m	shell
LXXVI	8-12-77	QtrA nondischarge	surface	flesh
LXXVII	8-12-77	QtrA nondischarge	surface	shell
LXXVIII	8-12-77	QtrA nondischarge	20m	flesh
LXXIX	8-12-77	QtrA nondischarge	20m	shell
LXXX	8-12-77	JKtB discharge	surface	flesh
LXXXI	8-12-77	JKtB discharge	surface	shell
LXXXII	8-12-77	JKtB discharge	20m	flesh
LXXXIII	8-12-77	JKtB discharge	20m	shell
LXXXIV	8-12-77	JKtB nondischarge	surface	flesh
LXXXV	8-12-77	JKtB nondischarge	surface	shell
LXXXVI	8-12-77	JKtB nondischarge	20m	flesh
LXXXVII	8-12-77	JKtB nondischarge	20m	shell
LXXXVIII	8-19-77	Flare StkA	surface	flesh
LXXXIX	8-19-77	Flare StkA	surface	shell
XC	8-19-77	Flare StkA	20m	flesh
XCI	8-19-77	Flare StkA	20m	shell
XCII	10-23-77	PfmA discharge	surface	flesh
XCIII	10-23-77	PfmA discharge	surface	shell
XCIV	10-22-77	PfmA discharge	20m	flesh
XCV	10-22-77	PfmA discharge	20m	shell
XCVI	10-23-77	PfmA nondischarge	surface	flesh
XCVII	10-23-77	PfmA nondischarge	surface	shell
XCVIII	10-22-77	PfmA nondischarge	20m	flesh

TABLE 7 (Continued)

Sample	Date	Location	Depth	Material
XCIX	10-22-77	PfmA nondischarge	20m	shell
C	10-23-77	QtrA discharge	surface	flesh
CI	10-23-77	QtrA discharge	surface	shell
CII	10-23-77	QtrA discharge	20m	flesh
CIII	10-23-77	QtrA discharge	20m	shell
CIV	10-23-77	QtrA nondischarge	surface	flesh
CV	10-23-77	QtrA nondischarge	surface	shell
CVI	10-23-77	QtrA nondischarge	20m	flesh
CVII	10-23-77	QtrA nondischarge	20m	shell
CVIII	10-27-77	JKtB discharge	surface	flesh
CIX	10-27-77	JKtB discharge	surface	shell
CX	10-27-77	JKtB discharge	20m	flesh
CXI	10-27-77	JKtB discharge	20m	shell
CXII	10-27-77	JKtB nondischarge	surface	flesh
CXIII	10-27-77	JKtB nondischarge	surface	shell
CXIV	10-27-77	JKtB nondischarge	20m	flesh
CXV	10-27-77	JKtB nondischarge	20m	shell
CXVI	2-1-78	PfmB discharge	surface	flesh
CXVII	2-1-78	PfmB discharge	surface	shell
CXVIII	2-1-78	PfmB discharge	20m	flesh
CXIX	2-1-78	PfmB discharge	20m	shell
CXX	2-28-78	PfmB nondischarge	surface	flesh
CXXI	2-28-78	PfmB nondischarge	surface	shell
CXXII	2-28-78	PfmB nondischarge	20m	flesh
CXXIII	2-28-78	PfmB nondischarge	20m	shell
CXXIV	2-28-78	QtrB discharge	surface	flesh
CXXV	2-28-78	QtrB discharge	surface	shell
CXXVI	1-27-78	QtrB discharge	20m	flesh
CXXVII	1-27-78	QtrB discharge	20m	shell
CXXVIII	2-28-78	QtrB nondischarge	surface	flesh
CXXIX	2-28-78	QtrB nondischarge	surface	shell
CXXX	1-27-78	QtrB nondischarge	20m	flesh
CXXXI	1-27-78	QtrB nondischarge	20m	shell
CXXXII	3-10-78	JKtB discharge	surface	flesh
CXXXIII	3-10-78	JKtB discharge	surface	shell
CXXXIV	3-10-78	JKtB discharge	20m	flesh
CXXXV	3-10-78	JKtB discharge	20m	shell
CXXXVI	3-10-78	JKtB nondischarge	surface	flesh
CXXXVII	3-10-78	JKtB nondischarge	surface	shell
CXXXVIII	3-10-78	JKtB nondischarge	20m	flesh
CXXXIX	3-10-78	JKtB nondischarge	20m	shell

TABLE 8

DISTRIBUTION OF n-ALKANES IN BARNACLE SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12	4.5				0.5		
C-13	6.3				2.3		
C-14	7.9		10.5		3.2		1.8
C-15	28.9	8.9	32.9	7.4	54.8	7.4	32.1
C-16	6.8	8.9	3.0	3.1	0.7	2.8	3.9
C-17		15.4	18.0	16.4	1.8	14.8	20.1
C-18	3.7	8.1	1.5	2.5	0.5	3.7	1.8
C-19	3.4	8.1	0.3	3.9	0.5	4.6	0.8
C-20	2.1	4.9	1.5	1.2	0.2	1.9	0.8
C-21	15.0	7.3	19.5	7.8	17.5	7.4	26.1
C-22	1.8	4.0	0.6	2.5	0.5	2.8	0.8
C-23	2.6	4.9	1.5	4.3	5.3	3.7	1.8
C-24	2.6	5.7	1.5	7.0	1.8	6.5	1.8
C-25	3.2	6.5	1.5	9.0	2.8	11.1	1.8
C-26	1.8	4.0	0.6	8.8	1.4	9.3	0.8
C-27	1.8	3.2	0.3	7.4	1.8	7.4	0.8
C-28	1.8	3.2	0.6	5.7	1.1	5.6	1.0
C-29	0.8	2.4	0.3	4.3	0.5	3.7	0.3
C-30	0.3	1.6		2.9	0.2	1.9	
C-31	1.8	1.6	1.5	2.0	1.1	1.9	0.8
C-32	0.8	0.8		1.2	0.5	0.9	
C-33	1.8	0.4	4.5	0.6	1.2		1.6
C-34				0.4		0.9	
C-35				1.6		1.9	
C-36							
C-37							

TABLE 8 (Continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12							
C-13		1.0				1.5	0.5
C-14		1.3		1.3		4.6	1.0
C-15	3.8	15.7	7.5	33.4	3.4	54.2	9.5
C-16	1.5	6.3	2.5	4.0	1.7	6.2	4.0
C-17	9.1	22.0	18.8	24.0	15.4		22.5
C-18	2.3	3.1	1.8	1.3	2.3	3.1	2.0
C-19	3.8	2.1	2.0	1.3	6.8	3.1	6.5
C-20	0.8	2.1	1.0	1.3	1.1	0.9	1.5
C-21	21.3	24.1	8.3	20.0	18.8	21.7	10.0
C-22	1.9	2.1	2.0	0.9	1.7	1.5	2.0
C-23	4.6	3.1	4.0	1.6	4.0	1.5	3.5
C-24	6.8	2.5	6.8	1.3	6.3	1.5	5.5
C-25	9.1	3.1	8.8	2.4	8.5		6.5
C-26	8.4	1.9	8.8	1.3	7.4		6.0
C-27	7.6	2.1	7.5	1.1	6.8		5.5
C-28	6.1	1.0	6.3	1.3	5.7		4.0
C-29	4.6	0.4	5.0	0.3	3.4		3.0
C-30	3.0	0.2	3.3	0.3	2.3		2.0
C-31	2.3		2.5	1.1	1.7		1.5
C-32	0.8	1.0	1.3	0.3	1.1		0.5
C-33	0.8	1.0	0.5	1.3	0.6		0.5
C-34	0.4	0.4	0.5		0.3		0.5
C-35	1.1	2.1	1.3	0.6		0.5	
C-36		1.0					
C-37							

TABLE 8 (Continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12							
C-13					4.1		
C-14	5.1				1.9		2.1
C-15	30.8	10.5	38.9	3.9	42.0	5.6	53.6
C-16	5.1	3.1	8.0	1.4	4.1	1.2	3.9
C-17	25.7	16.6		7.8		16.2	3.0
C-18	0.5	2.2	4.4	1.7	1.4	1.4	1.8
C-19		5.2	3.5	6.7	0.3	4.3	0.9
C-20		1.7		0.8	0.5	0.5	0.9
C-21	30.8	2.6	30.1	0.3	23.0	2.0	16.1
C-22	0.3	2.2	1.8	2.5	1.4	2.0	1.2
C-23	0.3	4.4	3.5	6.1	2.7	5.5	3.0
C-24	0.3	7.0	1.8	9.7	1.4	8.9	2.1
C-25	0.3	9.6	3.5	12.5	1.9	11.2	2.1
C-26		8.7	0.9	12.5	1.1	10.9	0.9
C-27		7.4	0.9	10.6	1.4	9.4	1.2
C-28		5.7	2.7	7.8	0.5	6.8	0.9
C-29		4.4		6.1	0.3	5.1	0.3
C-30		2.2		3.6	0.3	3.4	0.3
C-31		2.2		2.5	0.3	2.6	0.9
C-32		0.9		1.4		1.0	0.3
C-33	0.8	0.4		0.8	1.9	0.5	3.9
C-34		0.9		0.3	1.6	0.5	0.3
C-35		2.2		1.1	8.1	1.0	
C-36							
C-37							

TABLE 8 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12							
C-13							1.0
C-14							0.5
C-15	5.9	16.9	1.4	40.7	7.0		7.0
C-16	2.6	6.0	0.8	6.8	4.4		3.3
C-17	11.3	21.7	3.9		39.3	62.8	16.0
C-18	2.6	2.4	0.8	16.9	9.2	4.7	3.5
C-19	7.7	1.2	2.2		4.4	2.3	4.0
C-20	2.0		0.5	1.7	1.8		2.5
C-21	1.5	44.6	7.3	6.8	2.2	18.6	15.0
C-22	3.1	1.2	3.7	1.7	1.8	2.3	2.5
C-23	5.6	1.2	7.6	3.4	2.9	2.3	3.0
C-24	8.7	1.2	11.0	3.4	4.0	2.3	5.0
C-25	11.8	1.2	12.7	5.1	4.4	2.3	7.5
C-26	10.2	1.2	12.2	3.4	4.4	1.2	13.0
C-27	9.2	1.2	10.7	3.4	4.0	1.2	1.0
C-28	6.6		8.3	1.7	3.7		3.5
C-29	4.6		6.6		2.2		3.0
C-30	2.6		3.7	1.7	1.5		2.0
C-31	1.5		2.7		1.1		1.5
C-32	0.5		1.7		0.7		1.0
C-33	0.5		1.0	3.4			0.5
C-34	0.5		0.5		0.4		0.5
C-35	1.0		0.7		0.4		2.5
C-36							
C-37							

TABLE 8 (Continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV
C-12					1.7		
C-13					2.4	0.6	
C-14			1.4		5.9	0.6	
C-15	43.6	3.1	31.2	7.1	35.0	7.8	71.0
C-16	7.3	1.9	5.7	1.8	3.5	3.4	7.3
C-17	23.3	10.6	28.3	33.9	1.7	11.8	2.0
C-18	2.9	2.5	1.4	3.6	1.0	2.8	1.6
C-19	0.9	3.7	1.4	12.5	1.0	2.8	
C-20	0.9	0.9	0.6	1.8	0.3	1.1	0.8
C-21	11.6	0.9	21.2	7.1	18.2	12.9	2.0
C-22	0.9	2.5	1.4	1.8	1.7	1.7	0.8
C-23	0.9	5.0	2.8	1.8	3.5	4.5	
C-24	0.9	9.3	1.4	3.6	3.1	6.7	0.8
C-25	0.9	11.2	1.4	5.4	4.2	9.5	0.4
C-26		11.2		5.4	3.1	8.4	
C-27		9.3		3.6	3.1	7.3	
C-28		7.2		3.6	1.7	5.6	2.9
C-29		5.6		3.6	1.0	4.5	
C-30	0.9	3.7		1.8	0.3	2.8	
C-31	0.9	2.5	0.6	1.8	1.7	2.2	7.3
C-32	0.9	5.0	0.6		0.3	1.1	
C-33	3.5	1.2	0.6		4.9	0.6	2.0
C-34		0.6				0.3	0.8
C-35		1.7				1.1	
C-36							
C-37							

TABLE 8 (Continued)

Sample	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
C-12			3.5				
C-13			3.5		2.0	7.7	
C-14			3.5		1.0	3.8	1.6
C-15	4.8	2.4	15.7	22.7	35.0	38.5	26.0
C-16	2.0	2.4	4.3	2.3	3.0	3.8	4.9
C-17	8.8		17.4		7.0		27.6
C-18	2.0	2.4	3.5	2.3	3.0	1.9	4.9
C-19	4.4	4.8	3.5	18.2	2.0	11.5	6.5
C-20	2.0		1.7		1.0		
C-21	8.8	81.9	8.7	22.7	18.0	7.7	3.9
C-22	2.7		1.7	2.3	1.0	1.9	0.8
C-23	4.4		3.5	2.2	2.0	3.8	1.6
C-24	6.1	4.5	5.2	4.5	3.0	3.8	3.3
C-25	8.5	1.2	7.0	4.5	4.0	3.8	4.9
C-26	8.2	1.2	5.2	4.5	4.0	3.8	3.3
C-27	7.5	1.2	5.2	9.1	4.0	3.8	3.3
C-28	6.1	1.2	3.5		3.0	3.8	1.6
C-29	4.4		2.6	4.5	2.0		1.6
C-30	2.7				2.0		1.6
C-31	2.0		0.9		2.0		1.6
C-32	0.7				1.0		
C-33	0.3						
C-34	2.4						
C-35	6.8						
C-36	4.1						
C-37							

TABLE 8 (Continued)

Sample	XLIII	XLIV	XLV	XLVI	XLVII	XLVIII	XLIX
C-12							
C-13							
C-14		1.6					
C-15	14.0	24.4		4.2	6.5	9.9	0.6
C-16	4.7	3.3		1.9	5.6	1.2	26.8
C-17		11.4	81.9	11.1	65.7	8.6	61.2
C-18	4.7	4.9	2.9	1.9	2.8	2.5	1.5
C-19	14.0	3.3	8.8	2.8	5.6	6.2	3.8
C-20		0.8	0.6	1.9	0.8	2.5	0.3
C-21	41.9	26.0	5.8	1.9	7.6	2.5	5.1
C-22		0.8		1.9	0.5	1.2	0.3
C-23		1.6		4.6	0.8	6.2	0.1
C-24	2.3	3.3		9.3	0.8	14.8	0.1
C-25	4.7	4.9		20.4	0.8	24.7	0.1
C-26	4.7	3.3		7.4	0.8		
C-27	4.7	3.3		7.4	0.8		
C-28	4.7	3.3		9.3	0.5	13.6	
C-29		1.6		5.6		6.2	
C-30		0.8		1.9			
C-31		1.6					
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	L	LI	LII	LIII	LIV	LV	LVI
C-12							
C-13							
C-14							0.4
C-15	7.8	7.0	11.6	34.6	5.7		4.4
C-16	5.9	3.5		1.8	2.3		3.6
C-17	15.7	1.7	3.5	1.8	13.6	3.0	5.1
C-18	3.9	1.7	3.5	1.8	13.6	3.0	5.1
C-19	2.6	24.4	7.0	3.6	3.4	8.9	5.8
C-20	2.6	0.4	2.3	0.4	2.3	0.3	2.2
C-21	6.5	16.5	7.0	3.6	2.3	20.7	5.8
C-22	3.9	0.2	2.3	0.2	3.4	0.3	4.4
C-23	5.2	0.2	4.7	0.2	5.7	0.3	5.1
C-24	9.2	0.2	7.0	0.2	8.0	0.3	8.0
C-25	11.8	0.2	11.6	0.2	9.1	0.3	9.5
C-26	9.2	0.2	7.0	0.2	8.0	0.3	8.7
C-27	7.8	0.2	10.5	0.2	8.0	0.3	6.5
C-28	6.5	0.2		0.2	5.7	0.3	4.4
C-29	1.3				3.4		2.2
C-30					1.1		0.7
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	LVII	LVIII	LVIX	LX	LXI	LXII	LXIII
C-12				4.0			
C-13							
C-14				2.7			
C-15	45.3	53.8			7.0		
C-16	1.3			1.3	0.9		
C-17	3.8	7.7	1.2	10.7	7.0	6.1	0.5
C-18	1.3		0.4	1.3	0.9		0.3
C-19	2.5	2.6	0.8	9.4	0.9		0.3
C-20	1.9		0.4	0.7	0.9		0.3
C-21	2.5	2.6	1.2	2.7	0.9	12.1	1.2
C-22	2.5	1.3	2.9	2.7	3.5	3.0	4.3
C-23	6.3	2.6	6.1	6.7	5.2	6.1	8.0
C-24	6.3	3.8	12.3	4.0	9.6	6.1	11.7
C-25	5.0	3.8	14.3	6.7	12.2	6.1	13.5
C-26	6.3	5.1	15.6	5.4	12.2	12.1	14.3
C-27	3.8	5.1	13.5	28.2	11.3	18.2	12.8
C-28	5.0	5.1	10.2	8.1	9.6	30.3	11.0
C-29	3.8	3.8	9.4	2.7	7.8		9.2
C-30	2.5	2.6	5.3	1.3	4.3		6.4
C-31			4.1	1.3	3.5		3.8
C-32			1.6		1.7		1.7
C-33			0.4		0.9		0.5
C-34							0.2
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	LXIV	LXV	LXVI	LXVII	LXVIII	LXIX	LXX
C-12							
C-13					7.5		
C-14			2.9	0.2	9.0		
C-15	2.7	12.1	3.4	0.8	0.5		2.0
C-16		10.3	1.1	0.4	0.3		
C-17	13.4	10.0	4.0	2.5	11.8	1.3	10.8
C-18	7.0	7.3	1.1	0.8	1.0	0.2	0.5
C-19	7.8	6.6	1.1	1.9	1.3	0.3	1.0
C-20	7.5	5.6		3.3			
C-21	6.7	4.9	1.7	5.2	4.3	1.0	9.9
C-22	8.8	4.7	4.0	7.4	3.3	3.0	4.9
C-23	11.0	5.4	6.9	9.7	6.0	6.9	8.9
C-24	10.2	6.4	8.6	11.7	7.3	12.5	11.8
C-25	8.3	6.6	10.3	12.6	8.0	16.4	13.8
C-26	6.1	6.0	10.9	12.2	7.5	17.4	12.8
C-27	4.8	4.9	10.9	9.7	8.5	14.8	10.8
C-28	2.9	3.6	9.2	7.8	5.5	10.9	6.9
C-29	1.9	2.6	8.6	6.2	6.5	7.9	3.0
C-30	0.8	1.5	5.7	3.7	5.3	3.9	1.5
C-31	0.3	0.8	4.6	2.1	4.0	2.3	1.0
C-32	0.3	2.9	1.0	2.3	0.8	0.5	
C-33		0.1	1.1	0.6		0.3	
C-34		0.1	0.6	0.2			
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	LXXI	LXXII	LXXIII	LXXIV	LXXV	LXXVI	LXXVII
C-12							
C-13							
C-14							
C-15		16.3	2.5			16.4	
C-16			0.2			0.8	
C-17		20.4	3.9	5.3	3.5	22.7	2.1
C-18		1.4	0.3	0.8	0.6	0.4	0.1
C-19			2.1	0.8	0.9	1.6	0.4
C-20							
C-21	2.5	6.1	1.2	0.8	0.8	3.9	0.8
C-22	2.5	4.1	3.5	3.8	3.3	3.1	2.5
C-23	6.2	8.2	7.8	9.9	7.4	7.0	7.0
C-24	11.2	8.2	12.6	14.4	13.2	8.6	13.2
C-25	14.9	12.2	14.4	17.5	15.8	9.4	16.5
C-26	18.6	10.2	14.4	16.7	16.2	8.6	16.9
C-27	16.1	6.1	12.2	12.9	13.2	7.0	14.2
C-28	12.4	4.1	9.5	8.4	10.0	4.7	10.9
C-29	8.7	2.0	7.0	5.3	7.4	3.1	7.8
C-30	3.7	0.7	4.4	1.9	4.1	1.6	4.3
C-31	2.5		2.5	1.1	2.3	0.8	2.1
C-32	0.6		1.2	0.4	0.9	0.4	0.8
C-33			0.4		0.4		0.4
C-34			0.1				0.2
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	LXXVIII	LXXIX	LXXX	LXXXI	LXXXII	LXXXIII	LXXXIV
C-12							
C-13							
C-14				0.3			
C-15		1.2		1.1			19.0
C-16		1.2		0.3			1.0
C-17		3.1	3.1	1.1	0.9	4.8	24.0
C-18		1.8		2.3		0.3	0.5
C-19		1.8		0.6	9.4	0.5	5.0
C-20							
C-21		1.2	12.5	1.4	7.5	1.1	7.0
C-22	4.2	3.4	6.3	3.9	5.6	3.2	4.0
C-23	8.3	7.0	12.5	8.5	12.2	7.4	8.0
C-24	16.7	12.2	15.6	13.0	13.1	12.7	8.0
C-25	25.0	15.3	12.5	15.3	13.1	15.3	7.0
C-26	16.7	15.3	15.6	15.6	13.1	15.3	6.5
C-27	16.7	12.9	9.4	13.3	8.5	11.8	6.0
C-28	8.3	9.8	6.3	10.0	7.5	10.0	4.0
C-29	4.3	7.3	3.1	7.1	5.6	8.5	
C-30		3.4	3.1	3.4	1.9	4.8	
C-31		2.1		2.0	1.4	3.2	
C-32		0.9		0.7		1.3	
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	LXXXV	LXXXVI	LXXXVII	LXXXVIII	LXXXIX	XC	XCI
C-12							
C-13							
C-14							
C-15				38.6	1.6	7.1	0.8
C-16				1.0		1.2	0.3
C-17	0.6	5.4	2.4	15.5	4.2	2.4	5.0
C-18	0.2		0.8	1.0	0.5	1.2	1.7
C-19	0.4			1.0	0.5	1.2	0.7
C-20							
C-21	1.2	10.7	0.8	4.3	1.0	2.4	0.8
C-22	3.9	3.6	3.1	3.9	4.2	4.7	3.7
C-23	8.9	7.1	7.9	7.2	8.3	10.6	8.0
C-24	14.3	12.5	12.6	6.3	13.0	14.1	13.0
C-25	16.6	14.3	15.7	5.8	15.1	14.1	14.7
C-26	16.2	14.3	15.7	4.8	14.6	14.1	15.1
C-27	13.9	10.7	14.2	3.9	12.5	10.6	12.7
C-28	10.1	8.9	11.0	3.0	9.4	7.1	9.7
C-29	7.4	7.1	7.9	1.9	6.8	4.7	6.7
C-30	3.9	2.7	4.7	1.0	4.2	2.4	3.7
C-31	1.9	1.8	2.4	1.0	2.6	1.2	2.0
C-32	0.6	0.9	0.8		1.0	1.2	0.7
C-33					0.5		0.7
C-34							
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	XCII	XCIII	XCIV	XCV	XCVI	XCVII	XCVIII
C-12					0		
C-13							
C-14							
C-15	23.5						
C-16							
C-17	11.8	6.5	33.3	0.5		12.3	6.3
C-18	8.8						
C-19	8.8					5.3	
C-20						7.0	
C-21	2.9		33.3			17.5	
C-22	2.9	3.2		1.9		10.5	
C-23	5.9	9.7		5.7		28.1	
C-24	5.9	12.9		9.6		3.5	
C-25	5.9	12.9		11.5		1.8	
C-26	5.9	12.9		11.5		3.5	6.3
C-27	2.9	12.9		11.5		1.8	12.5
C-28	2.9	9.7	33.3	9.6		3.5	75.0
C-29	5.9	9.7		9.6		1.8	
C-30		3.2		7.7		1.8	
C-31	2.9	3.2		9.6		1.8	
C-32	2.9	3.2		5.7			
C-33				3.8			
C-34				1.9			
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	XCIX	C	CI	CII	CIII	CIV	CV
C-12							
C-13							
C-14							
C-15	1.8	23.5				14.3	
C-16		12.3				1.8	
C-17	2.7	23.5	1.0	10.3		10.7	
C-18		8.0				3.6	
C-19	0.9	4.9				3.6	
C-20	0.6	2.5					
C-21	0.6	2.5	0.5	20.6	0.7	7.1	
C-22	2.7	2.5	2.1		2.1	1.8	
C-23	5.5	2.5	5.2		5.7	3.6	7.0
C-24	9.1	2.5	9.4		8.6	3.6	14.0
C-25	10.9	2.5	12.6		11.4	3.6	14.0
C-26	11.8	2.5	13.6	2.1	12.9	3.6	14.0
C-27	10.9	2.5	12.6	25.9	12.9	10.7	14.0
C-28	9.1	3.7	11.5	41.2	11.4	25.0	9.3
C-29	9.1	1.2	10.5		10.0	3.6	9.3
C-30	7.3	1.2	7.3		7.1	3.6	9.3
C-31	9.1	1.9	7.3		8.6		7.0
C-32	4.5		3.1		4.3		2.3
C-33	2.7		2.1		2.9		
C-34	0.9		1.0		1.4		
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	CVI	CVII	CVIII	CIX	CX	CXI	CXII
C-12							
C-13							
C-14							
C-15	17.8						28.4
C-16							1.4
C-17	22.2		5.6	1.3	3.8	3.5	12.2
C-18			1.4				1.4
C-19	8.9		4.2				5.4
C-20	2.2						0.7
C-21	2.2	1.1	59.2	1.3	75.5	7.0	20.3
C-22	2.2	2.2	1.4	2.6		2.6	1.4
C-23	2.2	4.3	2.8	6.6		6.1	2.7
C-24	2.2	8.7	2.8	10.5	1.9	10.5	2.7
C-25	2.2	10.9	2.8	13.2	1.9	14.0	6.8
C-26	2.2	13.0	2.8	15.8	1.9	15.8	2.7
C-27	2.2	13.0	2.8	13.2	3.8	14.0	5.4
C-28	31.1	10.9	5.6	10.5	11.3	9.6	4.1
C-29	2.2	8.7	2.8	10.5		7.0	1.4
C-30	2.2	8.7	1.4	5.3		3.5	0.7
C-31	2.2	10.9	1.4	5.3		3.5	2.7
C-32		4.3	2.8	2.6		1.8	
C-33		2.2		1.3		0.9	
C-34		1.1					
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	CXIII	CXIV	CXV	CXVI	CXVII	CXVIII	CXIX
C-12					4.8		
C-13							
C-14					10.7		0.1
C-15	1.3	6.1	0.6	24.5	13.4		0.5
C-16				1.6	12.6		0.1
C-17	5.2	6.1	0.8	15.6	11.8		2.4
C-18		1.0		2.1	8.2	1.1	0.6
C-19		1.0	0.8	2.6	7.7	9.6	1.0
C-20			0.2	1.0	5.7	1.7	2.6
C-21	3.9	55.1	4.2	3.6	4.2	14.6	2.4
C-22	2.6	1.0	2.3	2.6	3.7	3.9	11.9
C-23	5.2	2.0	4.6	5.2	3.4	6.7	8.1
C-24	10.3	3.1	8.0	7.3	3.1	10.1	12.3
C-25	12.9	4.1	11.1	7.8	2.8	11.8	12.9
C-26	15.5	4.1	13.4	7.3	2.5	12.4	14.0
C-27	12.9	4.1	13.0	6.8	1.9	9.6	11.8
C-28	10.3	8.2	10.7	4.7	1.5	6.7	7.8
C-29	7.7	2.0	8.8	3.1	0.9	5.1	5.1
C-30	5.2	1.0	6.5	2.1	0.6	3.4	3.0
C-31	5.2	1.0	9.2	2.1	0.3	2.8	1.8
C-32	1.3		3.8		0.1	0.6	0.8
C-33	0.6		1.5				0.4
C-34			0.6				0.3
C-35							0.1
C-36							
C-37							

TABLE 8 (Continued)

Sample	CXX	CXXI	CXXII	CXXIII	CXXIV	CXXV	CXXVI
C-12							
C-13							
C-14		0.8					
C-15		3.4		0.2			
C-16		0.7		0.5			
C-17		5.6		3.1	1.1		
C-18		0.8		0.9			
C-19	1.6	2.7		2.6	3.6	0.2	
C-20	4.0	0.9		0.6	2.0	0.2	
C-21	11.2	2.0		4.0	10.3	0.9	
C-22	1.6	3.1	2.1	3.4	3.6	2.4	
C-23	5.6	6.8	3.2	7.9	10.3	6.6	
C-24	9.6	9.0	8.6	13.0	11.2	11.8	4.8
C-25	13.1	17.3	12.8	14.4	11.2	16.6	4.8
C-26	15.2	17.3	17.1	14.2	11.2	18.4	9.5
C-27	4.0	11.9	17.1	14.0	9.2	16.3	9.6
C-28	12.0	8.0	10.7	9.6	7.0	11.2	16.7
C-29	8.0	5.3	10.7	6.0	5.6	7.7	9.5
C-30	4.8	2.7	8.6	3.2	4.2	4.4	16.7
C-31	8.3	1.4	6.0	1.7	7.3	2.6	19.0
C-32	0.8	0.3	3.0	0.5	1.1	0.6	9.5
C-33		0.1		0.2		0.3	
C-34				0.1			
C-35				0.2			
C-36							
C-37							

TABLE 8 (Continued)

Sample	CXXVII	CXXVIII	CXXIX	CXXX	CXXXI	CXXXII	CXXXIII
C-12							
C-13							
C-14		7.9					
C-15	0.8						
C-16	0.7	0.5					
C-17	3.4	64.4	0.1				5.2
C-18	0.7	2.4	0.1				0.5
C-19	1.5	3.1	0.8				1.4
C-20	0.5	0.5	0.7				0.8
C-21	5.3	6.7	4.9		1.8	1.0	5.4
C-22	3.4	0.7	4.2	1.6	1.2	0.8	3.0
C-23	6.6	2.6	9.1	4.8	4.1	3.3	6.1
C-24	9.8	1.8	12.0	7.9	8.8	6.9	10.2
C-25	11.7	1.9	13.7	12.7	12.9	12.5	14.0
C-26	12.7	1.9	13.9	15.9	15.8	17.1	15.7
C-27	11.5	1.7	12.9	15.9	16.4	19.8	13.7
C-28	10.0	1.2	10.8	12.7	14.0	14.8	9.6
C-29	8.3	0.7	8.6	12.7	11.1	11.5	6.5
C-30	5.9	0.5	4.9	7.9	8.2	7.2	4.1
C-31	4.2	1.4	2.5	6.3	2.9	4.0	2.6
C-32	1.7	0.2	0.7	1.6	1.8	1.0	0.8
C-33	0.8		0.2		1.2		0.4
C-34	0.3						0.1
C-35							
C-36							
C-37							

TABLE 8 (Continued)

Sample	CXXXIV	CXXXV	CXXXVI	CXXXVII	CXXXVIII	CXXXIX
C-12						
C-13						
C-14						
C-15	10.9		13.3		0.6	
C-16						
C-17	30.2		6.3		3.1	
C-18	1.6		0.5		0.7	
C-19	3.1	0.4	2.6		2.3	
C-20	0.5	0.2	0.6		0.4	
C-21	32.8	9.1	3.1		31.4	30.8
C-22	1.0	2.3	2.7		2.3	1.0
C-23	2.1	5.3	5.5	2.6	5.1	3.4
C-24	2.1	9.6	8.9	5.3	7.6	6.2
C-25	2.6	12.6	10.9	8.5	9.4	10.1
C-26	2.6	14.3	11.8	15.9	10.3	11.5
C-27	2.6	13.0	10.4	15.9	8.8	11.5
C-28	2.1	10.9	8.2	15.9	6.5	8.7
C-29	2.1	8.7	6.7	12.7	5.0	7.2
C-30	1.6	6.4	4.3	12.7	3.3	4.8
C-31	1.6	4.7	2.7	5.3	2.1	3.4
C-32	0.5	1.7	0.9	5.3	0.7	1.4
C-33		0.9	0.5		0.4	
C-34		0.2	0.1		0.1	
C-35						
C-36						
C-37						

TABLE 9

ADDITIONAL ANALYTICAL DATA FOR BARNACLE SAMPLES

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	380	--	2.14	1.93
II	247	0.74	0.50	1.43
III	334	6.50	4.00	4.05
IV	244	0.33	0.17	1.83
V	571	70.0	7.67	8.43
VI	108	1.00	0.25	1.75
VII	383	4.29	3.57	6.87
VIII	263	0.67	0.33	2.13
IX	477	3.05	2.33	3.37
X	400	0.43	0.14	1.92
XI	375	3.33	5.00	6.52
XII	176	0.41	0.75	2.34
XIII	323	--	6.50	4.62
XIV	198	0.51	0.75	2.45
XV	389	2.40	10.0	7.85
XVI	229	0.13	0.40	1.89
XVII	565	--	3.60	4.14
XVIII	180	0.79	0.50	1.40
XIX	389	--	8.00	4.40
XX	587	0.32	0.63	1.73
XXI	330	80.0	5.50	5.80
XXII	196	0.50	0.40	1.54
XXIII	415	1.94	2.50	7.30
XXIV	591	0.43	0.20	1.31
XXV	295	--	0	1.68
XXVI	272	0.31	0.36	2.13
XXVII	215	0.67	2.00	8.52
XXVIII	199	0.44	0.29	1.68
XXIX	344	4.38	2.50	5.80
XXX	161	0.44	0.75	1.23
XXXI	353	4.25	7.60	7.00
XXXII	112	0.47	0.50	3.27
XXXIII	286	100	10.0	3.42
XXXIV	179	0.81	0.20	1.90
XXXV	2450	2.40	--	5.67
XXXVI	294	0.54	0.33	1.56
XXXVII	415	--	--	10.9
XXXVIII	115	4.20	1.00	2.12
XXXIX	220	--	--	5.29
XL	100	1.43	0.33	3.55
XLI	260	--	2.00	3.39
XLII	62	3.53	0.50	3.55
XLIII	215	--	--	3.74
XLIV	62	1.43	0.50	3.52
XLV	342	1.11	1.00	27.6
XLVI	216	0.96	0.50	1.38
XLVII	354	0.73	0.17	7.47

TABLE 9 (Continued)

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XLVIII	162	0.71	0.50	1.79
XLIX	784	0.71	0.42	2.45
L	153	0.83	0.67	1.43
LI	1149	0.38	0.50	14.63
LII	86	0.60	0.33	3.10
LIII	549	0.86	0.50	19.8
LIV	88	0.75	0.8	1.25
LV	338	0.55	0.25	21.22
LVI	138	0.66	0.43	1.67
LVII	795	69.0	3.0	2.69
LVIII	390	2.97	--	4.57
LIX	244	4.0	--	1.05
LX	745	71.25	5	2.17
LXI	287.5	1.63	--	1.30
LXII	825	15.0	--	0.94
LXIII	6005	1.67	0.67	0.99
LXIV	3740	4.20	0.92	1.31
LXV	3585	1.08	0.37	1.18
LXVI	870	5.29	1.0	1.12
LXVII	2575	0.46	0.63	1.06
LXVIII	1990	12.77	2.75	1.41
LXIX	1520	2.5	2.0	1.05
LXX	1015	5.73	5.0	25.2
LXXI	402.5	--	--	1.04
LXXII	735	8.6	3.0	2.50
LXXIII	1216.5	0.83	1.25	1.17
LXXIV	1315	12.29	3.5	1.16
LXXV	854	1.10	2.6	1.07
LXXVI	1280	8.28	10.0	2.56
LXXVII	2578.5	0.55	2.0	1.05
LXXVIII	1920	--	--	1.18
LXXIX	817	0.28	0.46	1.08
LXXX	640	10	--	1.13
LXXXI	884	1.5	0.2	1.02
LXXXII	532.5	8	--	1.42
LXXXIII	946.5	0.67	1.0	1.11
LXXXIV	1000	7.5	14.0	3.17
LXXXC	1034	2.0	1.0	1.04
LXXXVI	560	10.33	--	1.33
LXXXVII	635	0.67	1.0	1.05
LXXXVIII	1035	20.0	7.0	3.81
LXXXIX	960	3.0	2.0	1.13
XC	850	45.5	8.0	1.18
XCI	11960	0.27	0.30	1.09
XCII	170	25.5	--	2.4
XCIII	155	2.0	--	1.21
XCIV	30	7.0	--	2.0
XCV	522.5	2.0	--	1.09

TABLE 9 (Continued)

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XCVI	0	--	--	--
XCVII	285	0.57	--	2.35
XCVIII	800	6.0	--	0.23
XCIX	550	0.67	--	1.18
C	810	5.53	0.46	1.84
CI	955	1.5	--	1.08
CII	485	10.0	--	1.31
CIII	700	--	--	1.09
CIV	840	21.33	1.5	1.33
CV	215	--	--	1.05
CVI	225	8.2	--	1.5
CVII	460	--	--	1.04
CVIII	177.5	0.5	1.16	4.46
CIX	380	2.0	--	1.11
CX	265	7.0	--	5.63
CXI	570	0.5	--	1.28
CXII	740	47.8	5.0	5.73
CXIII	387.5	1.0	--	1.21
CXIV	245	0.12	1.0	4.44
CXV	2615	0.75	--	1.20
CXVI	3840	5.3	1.0	2.49
CXVII	6720	0.99	0.3	0.87
CXVIII	890	--	--	1.51
CXIX	39890	1.16	0.65	0.87
CXX	624	--	--	1.08
CXXI	1885	0.51	0.6	1.30
CXXII	233.5	--	--	1.0
CXXIII	655	1.64	0.67	1.18
CXXIV	354	4.25	--	1.46
CXXV	664	2.0	--	1.05
CXXVI	42	--	--	0.75
CXXVII	590	1.[illegible]	0.75	1.19
CXXVIII	4195	2.0	0.5	4.71
CXXIX	1631.5	3.0	0.67	1.12
CXXX	315	--	--	1.[illegible]
CXXXI	171	--	--	1.01
CXXXII	303.5	--	--	1.09
CXXXIII	856	0.49	0.5	1.23
CXXXIV	960	0.72	0.67	7.35
CXXXV	470	--	--	1.20
CXXXVI	875	1.24	0.75	1.63
CXXXVII	94.5	--	--	0.82
CXXXVII	828	0.65	0.83	2.14
CXXXIX	1040	--	--	1.97

TABLE 10

TABULATION OF SHRIMP SAMPLES

Sample	Date	Location	Species	Collection Method
I	08-09-76	S-2	brown shrimp (Penaeus aztecus)	trawl
II	08-09-76	P-7	white squid (Lolliguncula brevis)	trawl
III	08-10-76	P-7	brown shrimp (Penaeus aztecus)	trawl
IV	02-16-77	P-6	brown shrimp (Penaeus aztecus)	trawl
V	02-16-77	P-6	pink shrimp (Penaeus duorarum)	trawl
VI	02-16-77	P-6	sugar shrimp (Trachypenaeus similis)	trawl
VII	02-16-77	P-6	mantis shrimp (Squilla empusa)	trawl
VIII	02-16-77	P-6	white squid (Lolliguncula brevis)	trawl
IX	11-15-76	V-4	white squid (Lolliguncula brevis)	trawl
X	08-09-76	V-4	white squid (Lolliguncula brevis)	trawl
XI	10-18-77	Inter-rig	brown shrimp (Penaeus aztecus)	trawl
XII	10-18-77	Inter-rig	brown shrimp (Penaeus aztecus)	trawl
XIII	10-18-77	Inter-rig	brown shrimp (Penaeus aztecus)	trawl
XIV	10-18-77	Inter-rig	brown shrimp (Penaeus aztecus)	trawl
XV	10-18-77	Inter-rig	sugar shrimp (Trachypenaeus similis)	trawl
XVI	10-18-77	Inter-rig	chevron shrimp (Sicyonia dorsalis)	trawl

TABLE 10 (Continued)

Sample	Date	Location	Species	Collection Method
XVII	03-10-78	PfmB	brown shrimp (*Penaeus aztecus*)	trawl
XVIII	03-10-78	PfmB	sugar shrimp (*Trachypenaeus similis*)	trawl
XIX	03-10-78	PfmB	sugar shrimp (*Trachypenaeus similis*)	trawl
XX	03-10-78	PfmB	sugar shrimp (*Trachypenaeus similis*)	trawl
XXI	03-10-78	PfmA	chevron shrimp (*Sicyonia dorsalis*)	trawl
XXII	03-10-78	PfmA	sugar shrimp (*Trachypenaeus similis*)	trawl
XXIII	03-10-78	PfmA	sugar shrimp (*Trachypenaeus similis*)	trawl
XXIV	03-10-78	PfmA	sugar shrimp (*Trachypenaeus similis*)	trawl

TABLE 11

DISTRIBUTION OF n-ALKANES IN SHRIMP SAMPLES

Sample	I	II	III	IV	V	VI	VII	VIII
C-12								
C-13	8.3							
C-14	4.2							
C-15	8.3	16.0		2.2		3.2		5.1
C-16	12.5	0.4		4.5		6.5		
C-17	20.8	76.8	1.3	6.3	20.0	12.9	5.9	92.3
C-18	6.3	1.5		2.2	10.0	6.5	5.9	
C-19	4.2	0.8	6.7	6.3	10.0	6.5	11.8	
C-20	6.3	0.8	0.7	6.3	10.0	6.5		
C-21	4.2	0.8	1.3	9.0	20.0	16.1	47.1	
C-22	4.2	0.4	5.4	11.3	10.0	3.2	11.8	
C-23	4.2	0.8	12.2	13.5	10.0	6.5	5.9	
C-24	4.2	0.8	17.5	13.5	10.0	6.5	5.9	
C-25	4.2	1.1	17.5	9.0		6.5	5.9	
C-26	4.2		14.9	2.2		6.5		
C-27			10.8	2.2		6.5		
C-28	4.2		6.7			6.5		
C-29			4.1					
C-30			0.7					
C-31								
C-32								
C-33								
C-34								
C-35								
C-36								
C-37								

TABLE 11 (Continued)

Sample	IX	X	XI	XII	XIII	XIV	XV	XVI
C-12								
C-13								
C-14	1.5							
C-15	52.9	27.6					1.7	
C-16	6.4	0.5					1.7	
C-17	20.1	65.9			1.9		2.6	
C-18	2.7	1.4					2.6	
C-19	2.7	0.9					2.6	
C-20	0.9	1.4					1.7	
C-21	1.8	0.5					2.6	
C-22	1.8	0.5			1.9		3.4	
C-23	1.8	1.4	5.6	8.6	3.8	5.0	6.0	7.4
C-24	1.8		8.3	8.6	5.7	6.7	8.6	7.4
C-25	2.7		11.1	8.6	7.5	11.7	10.3	11.1
C-26	1.8		13.9	11.4	9.4	11.7	12.9	11.1
C-27			13.9	14.3	11.3	11.7	12.1	11.1
C-28			13.9	8.6	7.5	8.3	9.5	11.1
C-29			13.9	14.3	13.2	15.0	10.3	11.1
C-30			8.3	11.4	9.4	8.3	3.4	11.1
C-31			11.1	11.4	13.2	13.3	3.4	11.1
C-32			2.9	7.5	5	4.3	7.4	
C-33					7.5	3.3		
C-34								
C-35								
C-36								
C-37								

TABLE 11 (Continued)

Sample	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
C-12	0					0		
C-13								
C-14								
C-15								
C-16								
C-17								
C-18								
C-19								
C-20								
C-21		23.2	8.8		1.4		6.7	
C-22				2.5	2.7		4.4	
C-23		9.3	8.8	5.0	5.4		8.9	
C-24		4.7	11.8	10.0	9.5		8.9	9.5
C-25		11.6	17.6	12.5	13.5		11.1	19.0
C-26		9.3	17.6	17.5	17.6		13.3	23.8
C-27		9.3	17.6	17.5	17.6		13.3	19.0
C-28		9.3	11.8	12.5	13.5		11.1	19.0
C-29		9.3	5.9	10.0	9.5		8.9	9.5
C-30		4.7		5.0	4.0		4.4	
C-31		4.7		5.0	2.7		4.4	
C-32		4.7		2.5	2.7		4.4	
C-33								
C-34								
C-35								
C-36								
C-37								

TABLE 12

ADDITIONAL ANALYTICAL DATA FOR SHRIMP SAMPLES

Sample	Total n-Alkanes (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	0.24	1.00	1.33	1.17
II	1.32	--	--	24.6
III	2.45	0.52	--	1.18
IV	0.11	1.71	6.80	1.14
V	0.05	1.50	0	1.50
VI	0.08	2.50	2.00	1.37
VII	0.04	2.00	1.00	3.24
VIII	0.98	0	1.00	37.5
IX	5.48	5.45	0.67	4.67
X	2.17	--	--	25.3
XI	0.72	--	--	1.25
XII	0.70	--	--	1.33
XIII	0.53	1.0	--	1.41
XIV	0.60	--	--	1.50
XV	2.32	0.33	0.33	1.07
XVI	1.35	--	--	1.08
XVII	0	--	--	--
XVIII	0.43	--	--	2.07
XIX	0.68	--	--	1.43
XX	1.2	--	--	1.0
XXI	7.4	--	--	1.0
XXII	0	--	--	--
XXIII	0.23	--	--	1.14
XXIV	0.63	--	--	0.91

TABLE 13

TABULATION OF PLANKTON SAMPLES

Sample	Date	Location	Collection Method
I	05-24-76	N-6	bongo
II	05-24-76	P-7	bongo
III	05-24-76	S-10	bongo
IV	05-25-76	P-6	bongo
V	08-16-76	K-3	bongo
VI	08-16-76	N-6	bongo
VII	08-17-76	P-6	bongo
VIII	08-17-76	S-10	bongo
IX	12-03-76	H-2	neuston
X	12-03-76	H-4	neuston
XI	12-03-76	H-5	neuston
XII	12-03-76	H-6	neuston
XIII	12-03-76	B	neuston
XIV	12-03-76	C	neuston
XV	12-03-76	F	neuston
XVI	12-03-76	G	neuston
XVII	02-13-77	X	500m net (66ft)
XVIII	02-16-77	P	500m net (70ft)
XIX	07-13-77	PfmB	bongo
XX	07-13-77	PfmB	neuston
XXI	07-14-77	PfmA	bongo
XXII	07-14-77	PfmA	neuston
XXIII	07-14-77	Sat. III	bongo
XXIV	07-14-77	Sat. III	neuston
XXV	07-14-77	Sat. V	bongo
XXVI	07-14-77	Sat. V	neuston
XXVII	10-14-77	PfmB	bongo
XXVIII	10-14-77	PfmB	neuston
XXIX	10-14-77	PfmA	bongo
XXX	10-14-77	PfmA	neuston
XXXI	10-14-77	Sat. III	bongo
XXXII	10-14-77	Sat. III	neuston
XXXIII	10-14-77	Sat. V	bongo
XXXIV	10-14-77	Sat. V	neuston
XXXV	02-22-78	PfmB	bongo
XXXVI	02-22-78	PfmB	neuston
XXXVII	02-22-78	PfmA	bongo
XXXVIII	02-22-78	PfmA	neuston
XXXIX	02-22-78	Sat. III	bongo
XL	02-22-78	Sat. III	neuston
XLI	02-22-78	Sat. V	bongo
XLII	02-22-78	Sat. V	neuston

TABLE 14

DISTRIBUTION OF n-ALKANES IN PLANKTON SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12	2.9		2.6				
C-13	1.8		2.0				
C-14	1.5	3.6	2.0				
C-15	7.3	16.9	29.8	3.0	14.3	22.7	14.0
C-16	5.1	8.4	4.6	2.0	8.4	15.5	15.2
C-17	6.5	10.8	7.3	12.1	18.5	18.2	23.2
C-18	3.6	6.0	3.3	16.2	8.4	5.5	11.1
C-19	3.6	2.4	2.6	8.1	5.9	3.6	5.8
C-20			0.7	4.0	11.8	1.8	3.5
C-21	0.7	1.2	2.0	4.0	8.4	1.8	2.9
C-22	18.2	24.1	3.3	4.0	6.7	3.6	4.7
C-23	1.5	2.4	2.0	8.1	4.2	4.5	4.1
C-24	2.2	3.6	2.6	6.1	5.9	4.5	4.1
C-25				6.1		4.5	3.5
C-26		1.2	1.3	6.1		1.8	2.0
C-27	1.5	6.0	2.0	2.0		1.7	1.4
C-28	40.7	10.8	29.1	6.1		6.4	1.4
C-29	1.5		1.3	8.1	3.4	1.8	0.6
C-30	1.5	2.4	0.7	4.0	4.2	0.9	0.6
C-31							0.8
C-32							0.9
C-33							0.3
C-34							0.6
C-35							0.3
C-36							
C-37							

TABLE 14 (Continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12							
C-13							
C-14		2.3	0.2	1.4	1.3	0.9	0.3
C-15	18.5	9.3	1.8	14.2	13.2	5.2	0.4
C-16	9.2	7.0	0.9	5.3	3.5	4.3	0.3
C-17	13.8	9.3	2.2	24.9	30.7	8.7	1.2
C-18	7.7	4.7	0.4	7.1	2.2	5.2	0.3
C-19	4.6	4.7	0.9	5.3	4.4	4.3	0.4
C-20	3.1	2.3		1.4		2.2	0.6
C-21	3.1	1.2	0.2	1.4	0.9	2.2	1.2
C-22	4.6	4.7	0.2	3.6	3.5	4.3	4.5
C-23	4.6	4.7	0.2	3.6	4.4	5.2	8.9
C-24	4.6	7.0	1.6	5.3	6.6	8.7	13.1
C-25	12.3	11.6	1.8	5.3	8.8	8.7	15.5
C-26	0.8	7.0	1.1	5.3	8.8	9.5	14.0
C-27	4.6	7.0	10.3	3.6	6.6	4.3	15.2
C-28	4.6	9.3	0.9	3.6	4.4	8.7	8.9
C-29	3.1	2.3	9.9	1.4	0.9	4.3	4.5
C-30	0.8	4.7	1.3	1.4		3.5	2.4
C-31		1.2	45.8	1.4		4.3	1.8
C-32			1.3	1.4		0.9	2.7
C-33			18.0	1.4		2.2	1.2
C-34			0.4	1.4		0.9	0.9
C-35			0.2			0.9	0.9
C-36			0.2			0.9	0.6
C-37							0.3

TABLE 14 (Continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12					0.5	0.5	0.9
C-13					0.2	0.5	0.5
C-14	0.4				0.5	1.1	0.9
C-15	1.6	6.9			24.0	32.1	24.2
C-16	2.4	2.3			1.0	2.8	1.9
C-17	13.5	39.1	43.2	12.1	3.4	7.9	4.7
C-18	4.8	4.6	5.4	6.1	0.5	3.0	1.9
C-19	6.4	4.6	35.1	6.1	1.0	2.9	1.9
C-20	4.0	4.6	5.4	6.1	0.5	1.9	
C-21	4.3	1.1	5.4	6.1	1.0	3.0	1.9
C-22	4.8	1.1	5.4	6.1	2.5	2.9	1.9
C-23	5.6	1.1		6.1	4.9	3.6	2.8
C-24	7.2	2.3		9.1	7.2	3.0	2.8
C-25	8.0	2.3		12.1	5.5	3.4	2.8
C-26	7.2	3.4		12.1	8.8	3.6	3.7
C-27	6.4	2.3		12.1	8.1	4.7	4.7
C-28	5.5	3.4		6.1	7.4	4.3	5.6
C-29	4.0	1.1			6.4	4.9	6.5
C-30	3.2	1.1			4.9	3.8	5.6
C-31	2.7	1.1			3.4	2.9	7.4
C-32	2.4	1.1			3.9	2.3	5.6
C-33	2.4	1.1			2.5	3.0	5.6
C-34	1.6	2.3			2.0	1.9	2.8
C-35	1.0	3.4					3.7
C-36	0.8	4.6					
C-37		4.6					

TABLE 14 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12		0.1	3.1			0	
C-13	0.3	0.1	4.8				
C-14	1.2	1.4	6.1		0.4		
C-15	2.7	7.8	7.1	16.9	11.1		1.8
C-16	3.8	6.9	7.1		2.2		2.2
C-17	4.5	8.2	6.6	6.8	4.5		4.7
C-18	5.2	8.2	6.5		3.2		5.9
C-19	5.8	7.9	6.3		4.0		6.6
C-20	5.9	7.5	5.8		4.6		6.5
C-21	5.3	7.0	5.1	3.4	5.2		6.5
C-22	5.3	6.5	5.0	3.4	5.8		6.1
C-23	5.7	6.1	4.6	5.1	6.7		5.9
C-24	6.0	5.6	4.3	6.8	7.2		6.1
C-25	6.8	4.9	4.5	6.8	8.0		5.9
C-26	7.2	4.9	4.4	6.8	8.6		5.8
C-27	7.8	4.1	4.2	6.8	8.8		5.8
C-28	7.6	2.4	3.8	10.2	7.5		5.9
C-29	6.9	2.6	3.2	5.1	5.9		6.1
C-30	5.1	1.5	2.3	8.5	3.0		5.5
C-31	3.4	2.7	2.1	3.4	2.0		4.9
C-32	2.6	2.0	2.0	10.2	1.1		3.5
C-33	0.9	1.5	1.2		0.2		2.1
C-34							1.2
C-35							1.2
C-36							
C-37							

TABLE 14 (Continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV
C-12							0
C-13							
C-14							
C-15	2.5	1.1	76.8	1.1	75	2.3	
C-16	0.8	2.1		1.3		3.4	
C-17	3.3	3.6	21.4	2.7	25	4.4	
C-18	2.5	4.5		2.8		5.0	
C-19	3.3	5.4		3.2		4.7	
C-20	2.5	5.3		3.4		4.5	
C-21	2.5	5.6	1.8	3.8		4.2	
C-22	3.3	6.2		4.5		4.5	
C-23	3.3	6.4		5.1		4.5	
C-24	3.3	6.3		5.7		5.0	
C-25	3.3	9.0		7.0		5.0	
C-26	4.1	4.7		8.3		5.3	
C-27	4.1	8.1		9.7		5.9	
C-28	5.0	7.4		9.8		5.9	
C-29	6.6	8.3		10.2		6.5	
C-30	6.6	6.1		7.8		6.1	
C-31	8.3	4.7		6.6		6.2	
C-32	7.4	2.2		3.4		5.1	
C-33	9.9	1.8		1.7		4.0	
C-34	8.3	0.4		0.9		2.6	
C-35	5.8	0.6		0.8		3.4	
C-36	3.3					1.7	
C-37							

TABLE 14 (Continued)

Sample	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
C-12		0	0				
C-13							
C-14							
C-15	0.4						
C-16	0.8						
C-17	1.7			14.3	10.8		4.8
C-18	1.1				3.1		6.5
C-19	1.7				7.7		8.1
C-20	1.9				4.6		8.1
C-21	2.5				46.2	0.7	6.5
C-22	3.4				3.1	0.7	6.5
C-23	5.0				1.5	2.9	6.5
C-24	6.9				1.5	5.7	4.8
C-25	8.6				3.1	8.8	6.5
C-26	9.4				1.5	11.4	6.5
C-27	10.1			28.6	1.5	14.3	6.5
C-28	9.4			42.9	1.4	12.9	6.5
C-29	9.4			7.1	4.6	14.3	6.5
C-30	7.8				3.1	11.4	4.8
C-31	7.6			7.1	3.1	10.0	8.1
C-32	5.7				3.1	7.1	3.2
C-33	4.2						
C-34	2.3						
C-35							
C-36							
C-37							

TABLE 15

ADDITIONAL ANALYTICAL DATA FOR PLANKTON SAMPLES

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	1375	0.60	0.50	0.41
II	830	0.90	0.33	0.70
III	1510	0.80	0.60	2.47
IV	240	0.90	0.50	1.06
V	1190	0.90	0.50	1.20
VI	1100	1.00	0.50	1.50
VII	858	1.05	0.35	1.33
VIII	650	1.00	0.50	1.83
IX	215	8.00	0.50	1.04
X	2225	3.60	0.50	11.05
XI	141	2.91	0.50	1.69
XII	228	0.18	0.40	2.30
XIII	231	11.25	0.83	1.00
XIV	3360	5.00	2.00	1.06
XV	628	0.76	0.40	1.25
XVI	435	0.53	0.75	2.25
XVII	370	0.56	0.50	5.17
XVIII	825	0	0.50	1.19
XIX	1020	4.0	0.6	1.53
XX	1325	1.82	0.7	2.22
XXI	5375	15.15	0.75	1.99
XXII	11610	1.18	1.03	1.00
XXIII	3915	0.97	0.31	1.12
XXIV	22575	0.65	0.66	0.98
XXV	295	11.1	--	1.19
XXVI	6690	1.35	0.35	1.30
XXVII	0	--	--	--
XXVIII	8520	0.35	0.36	1.05
XXIX	3025	3.0	1.33	1.12
XXX	22225	0.88	0.62	1.21
XXXI	560	2.44	--	--
XXXII	5280	0.93	0.47	.08
XXXIII	40	5.0	--	--
XXXIV	8860	0.69	0.86	1.04
XXXV	0	--	--	--
XXXVI	52400	0.67	0.33	1.05
XXXVII	0	--	--	--
XXXVIII	0	--	--	--
XXXIX	140	5.0	--	1.33
XL	1300	3.0	0.5	3.64
XLI	3500	--	--	1.03
XLII	6200	1.0	0.5	1.14

TABLE 16

TABULATION OF FISH SAMPLES

Sample	Date	Location	Species	Tissue
I	8-9-76	S-2	sand seatrout (Cyonoscion arenarius)	muscle
II				liver
III	8-9-76	S-3	blackfin searobin (Prionotus rubio)	muscle
IV				liver
V	8-9-76	S-3	red snapper (Lutjanus campechanus)	muscle
VI				liver
VII	8-9-76	V-4	southern kingfish (Menticirrhus americanus)	muscle
VIII				liver
IX	8-9-76	V-4	inshore lizardfish (Synodus foetens)	muscle
X				liver
XI	8-9-76	P-7	inshore lizardfish (Synodus foetens)	muscle
XII				liver
XIII	8-9-76	P-7	red snapper (Lutjanus campechanus)	muscle
XIV				liver
XV	8-9-76	P-7	sand seatrout (Cyonoscion arenarius)	muscle
XVI				liver
XVII	8-10-76	P-5	blackfin searobin (Prionotus rubio)	muscle
XVIII				liver
XIX	8-10-76	P-7	longspine porgy (Stenotomus caprinus)	muscle
XX	8-11-76	J-9	Atlantic midshipman (Porichthys porosissimus)	muscle
XXI				liver
XXII	1-21-77	Pfm B	bluefish (Pomatomus saltatrix)	muscle
XXIII				liver
XXIV	1-21-77	Pfm B	bluefish (Pomatomus saltatrix)	muscle
XXV				liver
XXVI	2-15-77	X-3	Atlantic croaker (Micropogon undulatus)	muscle
XXVII	2-15-77	X-3	sea catfish (Arius felis)	muscle
XXVIII				liver
XXIX	2-15-77	X-3	sand seatrout (Cyonoscion arenarius)	muscle
XXX				liver

TABLE 16 (Continued)

Sample	Date	Location	Species	Tissue
XXXI	2-16-77	P-6	largescale lizardfish	muscle
XXXII			(*Saurida brasiliensis*)	liver
XXXIII	2-16-77	P-6	sea catfish	muscle
XXXIV			(*Arius felis*)	liver
XXXV	2-16-77	P-6	roughback batfish	muscle
XXXVI			(*Ogcocephalus parus*)	liver
XXXVII	2-16-77	P-6	southern hake	muscle
XXXVIII			(*Urophycis floridanus*)	liver
XXXIX	2-16-77	P-6	rock seabass	muscle
XL			(*Centropristis philadelphica*)	liver
XLI	2-16-77	P-6	dwarf sandperch	muscle
XLII			(*Diplectrum bivittatum*)	liver
XLIII	2-16-77	P-6	pigfish	muscle
XLIV			(*Orthopristis chrysoptera*)	liver
XLV	2-16-77	P-6	Atlantic croaker	muscle
XLVI			(*Micropogon undulatus*)	liver
XLVII	2-16-77	P-6	gulf butterfish	muscle
			(*Peprilus burti*)	
XLVIII	2-16-77	P-6	smoothead scorpionfish	muscle
			(*Scorpaena calcarata*)	
XLIX	2-16-77	P-6	bandtail searobin	muscle
			(*Prionotus ophryas*)	
L	2-16-77	P-6	bay whiff	muscle
			(*Citharichthys spilopterus*)	
LI	2-16-77	P-6	dusky flounder	muscle
LII			(*Syacium papillosum*)	liver
LIII	2-16-77	P-6	blackcheek tonguefish	muscle
			(*Symphurus plagiusa*)	
LIV	2-16-77	Pfm A	pigfish	muscle
LV			(*Orthopristis chrysoptera*)	liver
LVI	2-16-77	Pfm A	Atlantic spadefish	muscle
LVII			(*Chaetodipterus faber*)	liver
LVIII	2-16-77	Pfm B	leopard toadfish	muscle
LIX			(*Opsanus pardus*)	liver

TABLE 16 (Continued)

Sample	Date	Location	Species	Tissue
LX	3-2-77	Jkt K	sheepshead	muscle
LXI			(*Archosargus probatocephalus*)	liver
LXII	3-2-77	Jkt N	sheepshead	muscle
LXIII			(*Archosargus probatocephalus*)	liver
LXIV	3-2-77	Jkt M	sheepshead	muscle
LXV			(*Archosargus probatocephalus*)	liver
LXVI	7-28-77	PfmA	yellow chum	muscle
LXVII			(*Kythoses incisor*)	liver
LXVIII	7-28-77	PfmA	yellow chum	muscle
LXIX			(*Kythoses incisor*)	liver
LXX	7-28-77	PfmA	Atlantic spadefish	muscle
LXXI			(*Chaetodipterus faber*)	liver
LXXII	7-28-77	PfmA	Atlantic spadefish	muscle
LXXIII			(*Chaetodipterus faber*)	liver
LXXIV	7-28-77	PfmA	Atlantic spadefish	muscle
LXXV			(*Chaetodipterus faber*)	liver
LXXVI	7-28-77	PfmA	tom tate	muscle
LXXVII			(*Haenulon auroliniatum*)	liver
LXXVIII	7-28-77	PfmA	bluefish	muscle
LXXIX			(*Pomatomus saltratrix*)	liver
LXXX	7-28-77	PfmA	gray triggerfish	muscle
LXXXI			(*Balistes capriscus*)	liver
LXXXII	7-28-77	PfmA	red snapper	liver
			(*Lutjanus campechanus*)	
LXXXIII	7-29-77	JktB	Atlantic spadefish	muscle
LXXXIV			(*Chaetodipterus faber*)	liver
LXXXV	7-29-77	JktB	belted sand bass	muscle
			(*Serranus subligarus*)	
LXXXVI	7-29-77	JktB	red snapper	muscle
LXXXVII			(*Lutjanus campechanus*)	liver
LXXXVIII	7-29-77	JktB	red snapper	muscle
LXXXIX			(*Lutjanus campechanus*)	liver
XC	7-29-77	JktB	gray triggerfish	muscle
XCI			(*Balistes capriscus*)	liver

TABLE 16 (Continued)

Sample	Date	Location	Species	Tissue
XCII	7-29-77	JktB	pinfish (*Lagodon rhomboides*)	muscle
XCIII	7-29-77	JktB	sharksucker	muscle
XCIV			(*Echeneis naucrates*)	liver
XCV	10-27-77	PfmA	crested blenny (*Hypleurochilas geminatus*)	
XCVI	10-27-77	PfmA	red snapper	muscle
XCVII			(*Lutjanus campechanus*)	liver
XCVIII	10-27-77	PfmA	Atlantic spadefish	muscle
XCIX			(*Chaetodipterus faber*)	liver
C	10-27-77	PfmA	Sheepshead	muscle
CI			(*Archosargus probatocephalus*)	liver
CII	10-27-77	QtrA	crested blenny (*Hypleurochilus geminatus*)	
CIII	10-27-77	QtrA	red snapper	muscle
CIV			(*Lutjanus campechanus*)	liver
CV	10-27-77	QtrA	Atlantic spadefish	muscle
CVI			(*Chaetodipterus faber*)	liver
CVII	10-27-77	QtrA	sheepshead	muscle
CVIII			(*Archosargus probatocephalus*)	liver
CIX	10-28-77	JktB	crested blenny (*Hypleurochilus geminatus*)	
CX	10-28-77	JktB	Atlantic spadefish	muscle
CXI			(*Chaetodipterus faber*)	liver
CXII	10-28-77	JktB	sheepshead	muscle
CXIII			(*Archosargus probatocephalus*)	liver
CXIV	1-29-78	PfmB	red snapper	muscle
CXV			(*Lutjanus campechanus*)	liver
CXVI	2-2-78	PfmB	Atlantic spadefish	muscle
CXVII			(*Chaetodipterus faber*)	liver
CXVIII	2-2-78	PfmB	sheepshead	muscle
CXIX			(*Archosargus probatocephalus*)	liver
CXX	2-2-78	PfmB	seaweed blenny (*Blennius marmoreus*)	

TABLE 16 (Continued)

Sample	Date	Location	Species	Tissue
CXXI	2-28-78	PfmB	crested blenny (*Hypleurochilus geminatus*)	
CXXII CXXIII	2-28-78	QtrB	Atlantic spadefish (*Chaetodipterus faber*)	muscle liver
CXXIV CXXV	2-28-78	QtrB	sheepshead (*Archosargus probatocephalus*)	muscle liver
CXXVI	2-28-78	QtrB	crested blenny (*Hypleurochilus geminatus*)	
CXXVII	2-28-78	QtrB	crested blenny (*Hypleurochilus geminatus*)	
CXXVIII CXXIX	3-10-78	JktB	red snapper (*Lutjanus campechanus*)	muscle liver
CXXX CXXXI	3-10-78	JktB	Atlantic spadefish (*Chaetodipterus faber*)	muscle liver
CXXXII CXXXIII	3-10-78	JktB	sheepshead (*Archosargus probatocephalus*)	muscle liver
CXXXIV	3-10-78	JktB	crested blenny (*Hypleurochilus geminatus*)	
CXXXV	3-10-78	JktB	crested blenny (*Hypleurochilus geminatus*)	

TABLE 17.

DISTRIBUTION OF n-ALKANES IN FISH SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12							
C-13							
C-14	2.3						
C-15	41.0		87.5		69.8	16.0	12.1
C-16	4.3				1.9		
C-17	38.3	70.2	12.5		18.9		19.4
C-18	0.8	9.2			2.8	8.0	3.6
C-19	5.1	4.6			1.9	8.0	3.6
C-20	0.8	4.6			1.9	8.0	5.8
C-21	0.4	4.6		100	1.9	12.0	0.5
C-22	0.4	2.3			0.9	8.0	3.6
C-23	2.3	4.6				8.0	5.8
C-24	1.2					8.0	8.2
C-25	1.6					16.0	12.1
C-26	0.8					8.0	8.2
C-27	0.6						12.1
C-28	0.2						4.8
C-29							
C-30							
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12							
C-13							
C-14			0.8		0.1		
C-15		44.6	89.7	65.7	55.4	20.0	55.2
C-16		0.8	3.1	1.0	0.4	6.7	
C-17	8.0	43.0	0.4	31.4	43.3	46.7	20.7
C-18	8.0	0.8	0.9	1.0	0.1	6.7	3.4
C-19		1.7	3.1	1.0	0.4	6.7	3.4
C-20	8.0	0.8	0.5		0.1	6.7	
C-21	24.0	0.8	0.7		0.1	6.7	3.4
C-22	8.0	0.8	0.1				6.9
C-23	8.0	1.7	0.6		0.2		6.9
C-24	8.0	1.7					
C-25	8.0	1.7	0.1				
C-26	4.0	0.8					
C-27	16.0	0.8					
C-28							
C-29							
C-30							
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12							
C-13							
C-14							
C-15	36.3	41.7	79.6	55.3	51.0	45.5	16.7
C-16	0.9	8.3	0.3		2.0	4.5	
C-17	57.4		1.3	1.9	20.4	22.7	37.6
C-18	0.5	8.3	1.3	4.8	2.0	4.5	2.2
C-19	2.5	8.3	2.1	3.4	2.0	2.3	
C-20	0.5	4.2	0.5	3.4	4.1	2.3	
C-21	0.2	4.2	1.1	2.4	2.0		2.2
C-22	0.1	4.2	5.1	3.8	2.0	2.3	2.2
C-23	0.7	4.2	0.5		5.1	2.3	4.4
C-24	0.1	4.2	1.1	0.5	6.1		10.1
C-25	0.5	4.2	1.9	1.0	3.1	9.1	10.1
C-26	0.1	4.2	1.3	1.0		2.3	10.1
C-27	0.1	4.2	1.3	1.4		2.3	4.4
C-28	0.1						
C-29				0.5			
C-30				1.0			
C-31			2.4	1.4			
C-32							
C-33				13.9			
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12							
C-13			0.5	2.1			
C-14	0.2	0.2	1.0	2.4			
C-15	26.2	23.6	12.0	16.4		9.7	
C-16	2.2	2.1	1.9	1.7		9.7	
C-17	27.3	12.9	69.5	32.8	45.5	51.6	3.1
C-18	1.6	2.1	1.6	1.7	9.1	3.2	
C-19	3.3	1.1	2.8	1.7	9.1	6.5	
C-20	1.6	2.1	0.5	1.4	9.1		
C-21	1.1	2.1	0.4	6.3	9.1	6.5	62.5
C-22	1.1	2.1	0.2	1.0	9.1		
C-23	1.6	2.1	0.5	1.7	9.1		3.1
C-24	3.3	4.3	0.7	2.1			3.1
C-25	3.3	8.6	0.9	3.5		6.5	6.3
C-26	3.3	4.3	1.0	2.4			3.1
C-27	3.3	3.2	1.0	1.4		6.5	9.4
C-28	3.3	5.4	1.0	14.6			3.1
C-29	3.3	2.1	1.0	1.7			3.1
C-30	3.3	2.1	0.9	0.7			3.1
C-31	3.3	17.2	0.9	4.2			
C-32	3.3	2.1	0.9				
C-33	2.2		0.4				
C-34	1.1		0.2				
C-35	1.1		0.2				
C-36							
C-37							

TABLE 17 (Continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV
C-12	2.1						
C-13	4.2						
C-14	1.6			0.6			
C-15	40.4		25.2	86.2	3.8		
C-16	8.4	3.7	1.9	3.3	3.8	5.7	7.7
C-17	6.3	3.7	18.9	0.6	80.2	8.6	7.7
C-18	7.4	1.8	1.3	1.5	0.8	5.7	3.8
C-19	6.3	0.9	1.9	3.8	1.9	2.9	
C-20	3.2			0.5			
C-21	2.1			0.3	3.8	22.9	
C-22	0.5		1.9	0.1			
C-23	1.1		4.4	2.1		5.7	
C-24	0.5		10.1	0.1		5.7	
C-25	0.5		10.1	0.4	3.8	8.6	61.5
C-26	0.5		10.1	0.2		5.7	
C-27	0.5	7.3	6.3	0.1	1.9	14.3	
C-28	0.5	12.8	5.0	0.1		8.6	7.7
C-29	10.6	36.7	1.9			2.9	7.7
C-30	0.5	18.3	1.3			2.9	3.8
C-31	2.6	14.7					
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
C-12					0		
C-13							
C-14							
C-15	0.6		6.3			14.3	
C-16	0.6			14.3		14.3	
C-17	1.3	4.5	6.3	85.7		57.1	24.8
C-18	0.3	4.5				14.3	9.9
C-19		4.5					2.0
C-20			12.5				
C-21	74.0						5.9
C-22		2.3	12.5				23.8
C-23			12.5				29.7
C-24	0.6	2.3	12.5				
C-25	1.9	4.5	12.5				2.0
C-26	1.6	4.5	12.5				2.0
C-27	3.2		6.3				
C-28	1.3	72.7	6.3				
C-29	3.2						
C-30	1.9						
C-31	9.1						
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	XLIII	XLIV	XLV	XLVI	XLVII	XLVIII	XLIX
C-12		0					
C-13							
C-14					1.5		
C-15	11.1			1.3	56.7	14.3	33.3
C-16	5.6			1.3	2.2	14.3	16.7
C-17	77.8			3.8	3.0	28.6	16.7
C-18	5.6				1.5	14.3	33.3
C-19					19.4	14.3	
C-20				2.5	1.5		
C-21				21.5	7.5		
C-22				1.3			
C-23				2.5	1.5		
C-24			20.0	2.5			
C-25			20.0	3.8	5.2		
C-26			20.0	5.1			
C-27			20.0	5.1			
C-28			20.0	8.9		14.3	
C-29				31.6			
C-30				8.9			
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	L	LI	LII	LIII	LIV	LV	LVI
C-12					0		
C-13							
C-14							1.3
C-15			3.3	2.4			31.6
C-16			3.3	2.4			2.5
C-17	12.1		3.3	2.4			
C-18			6.7	2.4			40.5
C-19				2.4			3.8
C-20	5.1	7.7	6.7	2.4			2.5
C-21				2.4			1.3
C-22	10.1	7.7	16.7	7.1			1.3
C-23	12.1	11.5	3.3	9.5			2.5
C-24	20.2	15.4	6.7	11.9			2.5
C-25	12.1	15.4	10.0	14.3		4.5	2.5
C-26	12.1	15.4	10.0	11.9		11.4	2.5
C-27	5.1	7.7	6.7	9.5		2.3	2.5
C-28	5.1	7.7	10.0	9.5		4.5	2.5
C-29	2.0	3.8	6.7	7.1		13.6	
C-30	2.0	3.8	3.3	2.4		59.1	
C-31	2.0	3.8				4.5	
C-32			3.3				
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	LVII	LVIII	LIX	LX	LXI	LXII	LXIII	LXIV	LXV
C-12									
C-13									
C-14						1.1			
C-15	5.3	10.0	2.6	1.6		16.3	3.6	14.2	
C-16		10.0	2.6	1.6	2.0	5.4	3.6	14.2	
C-17		5.0		16.4	2.0	21.7	3.6	71.6	
C-18	8.0	5.0	3.8	8.2	2.0	2.2			
C-19	1.3	5.0	1.3	6.6		2.2			
C-20	2.7		2.6	4.1		1.1			
C-21	60.0	10.0	28.2	1.6	78.4	1.1	16.1		
C-22	2.7	10.0	28.2	1.6		1.1			2.5
C-23	4.0	5.0	2.6	1.6		3.3			8.4
C-24	4.0	10.0	3.8	8.2		5.4			14.8
C-25	4.0	20.0	5.1	12.3	3.9	8.7	1.4		19.0
C-26	2.7	5.0	2.6	9.8	2.0	5.4	1.4		18.1
C-27	1.3	5.0	6.4	8.2	2.0	5.4	1.4		15.2
C-28	4.0		5.1	8.2	3.9	6.5	1.4		10.5
C-29			5.1	4.1	2.0	4.3	3.6		6.3
C-30				4.1	2.0	2.2	3.6		2.1
C-31						4.3			1.3
C-32				1.6		2.2			
C-33									
C-34									
C-35									
C-36									
C-37									

TABLE 17 (Continued)

Sample	LXVI	LXVII	LXVIII	LXIX	LXX	LXXI	LXXII
C-12						0	
C-13					21.1		
C-14					1.8		1.9
C-15		5.4					52.4
C-16							1.9
C-17	51.3	1.8	34.1	2.3	16.7		10.1
C-18	3.3	0.6	6.0		0.9		0.7
C-19	4.0						1.1
C-20	2.6	0.6	2.4				0.4
C-21	3.0	0.9	2.4		0.9		0.6
C-22	3.3	3.0	3.0	2.3	2.6		0.9
C-23	4.0	4.2	5.4	9.3	5.3		2.6
C-24	3.3	6.0	6.0	2.3	7.0		3.4
C-25	3.6	8.4	7.8	4.7	8.8		4.1
C-26	3.3	10.7	7.8	2.3	8.8		4.5
C-27	4.3	14.3	8.4	2.3	7.9		4.1
C-28	4.3	18.5	7.2	55.8	6.1		6.7
C-29	3.6	14.9	6.0	9.3	4.4		2.2
C-30	1.3	6.6	1.8	4.7	3.5		1.1
C-31	0.7	4.2	1.8	4.7	2.6		0.6
C-32	4.0				1.8		0.6
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	LXXIII	LXXIV	LXXV	LXXXVI	LXXXVII	LXXXVIII	LXXXIX
C-12			0		0		0
C-13							
C-14							
C-15						12.3	
C-16						1.5	
C-17		31.4		9.3		44.6	
C-18		3.9		0.9		1.5	
C-19		3.9		2.8		3.1	
C-20	7.4			0.5		0.8	
C-21	3.7	2.0		0.5		3.1	
C-22	22.2	3.9		1.9		1.5	
C-23	37.0	7.8		2.8		3.1	
C-24	3.7	7.8		4.6		3.8	
C-25	3.7	7.8		5.6		6.2	
C-26	3.7	7.8		6.5		4.6	
C-27	3.7	5.9		8.3		4.6	
C-28	7.4	7.8		11.1		2.3	
C-29	3.7	5.9		13.0		3.1	
C-30	3.7	3.9		11.1		1.5	
C-31				11.1		1.5	
C-32				5.6		0.8	
C-33				4.6			
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	LXXX	LXXXI	LXXXII	LXXXIII	LXXXIV	LXXXV	LXXXVI
C-12		6.3					
C-13							
C-14		6.3					
C-15		2.1					
C-16							
C-17	1.5	18.8	43.8	8.7		6.8	20.1
C-18		20.8	3.1				8.6
C-19			1.6				1.4
C-20	0.7						
C-21	1.5	4.2		2.2			2.2
C-22	4.4	2.1	1.6	6.5	14.3	1.7	4.3
C-23	7.3	6.3	4.7	8.7	14.3	6.8	5.8
C-24	11.7	6.3	6.3	13.0	28.6	10.2	8.6
C-25	14.6	8.3	7.8	13.0	14.3	13.6	10.1
C-26	14.6	8.3	9.8	13.0	14.3	10.2	10.1
C-27	13.1	8.3	10.9	10.9	14.3	10.2	8.6
C-28	10.2	2.1		13.0		40.7	7.2
C-29	8.8			6.5			5.8
C-30	5.8			2.2			2.9
C-31	2.9		6.3	2.2			2.9
C-32	1.5		4.7				1.4
C-33	1.5						
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	LXXXVII	LXXXVIII	LXXXIX	XC	XCI	XCII	XCIII
C-12					0		
C-13							
C-14							
C-15							
C-16							
C-17	25.0	23.8	33.0	1.6		9.2	1.5
C-18	5.0	7.9	8.2				0.4
C-19	7.5		6.2	0.6			0.4
C-20							
C-21		1.0	1.0	1.9		0.3	1.3
C-22	2.5	3.0	3.1	6.8		4.6	4.3
C-23	5.0	5.9	6.2	11.0		9.2	8.6
C-24	7.5	11.9	6.2	14.2		12.3	12.9
C-25	10.0	11.9	6.2	16.1		15.3	15.9
C-26	7.5	11.9	4.1	14.2		15.3	16.1
C-27	7.5	9.9	4.1	12.3		12.3	15.1
C-28	12.5	5.9	10.3	12.9		9.2	10.8
C-29	7.5	5.0	4.1	5.2		6.1	6.5
C-30	2.5	2.0	2.1	1.9		3.1	2.8
C-31			5.7	1.3		3.1	2.2
C-32							0.9
C-33							0.4
C-34							
C-35							
C-36							
C-37							

TABLE 71 (Continued)

Sample	XCIV	XCV	XCVI	XCVII	XCVIII	XCIX	C
C-12							
C-13							
C-14							
C-15							
C-16				4.7	9.5		
C-17	5.6		6.5				18.4
C-18				1.9	6.3		4.1
C-19							2.0
C-20							
C-21	5.6	0.7	2.6	1.9	6.3		4.1
C-22	3.7	1.4	3.9	0.9	4.8	5	4.1
C-23	11.1	4.1	6.5	1.9	4.8	10	6.1
C-24	7.4	6.9	10.4	1.9	6.3	15	6.1
C-25	11.1	8.3	11.7	2.8	9.5	20	6.1
C-26	11.1	8.3	11.7	2.8	9.5	20	6.1
C-27	7.4	8.3	11.7	3.7	12.7	10	10.2
C-28	11.1	8.3	9.1	4.7	9.5	10	6.1
C-29	11.1	11.0	9.1	14.0	6.3	5	8.2
C-30		11.0	5.2	11.2	6.3	5	8.2
C-31	14.8	11.0	6.5	39.2	3.2		6.1
C-32		9.7	2.6	8.4	4.8		4.1
C-33		5.5	2.6				
C-34		5.5					
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	CI	CII	CIII	CIV	CV	CVI	CVII
C-12	0					0	
C-13							
C-14							
C-15							
C-16							
C-17		7.9	9.6				
C-18							
C-19							
C-20							
C-21							
C-22							
C-23		7.9	9.6		9.7		
C-24		7.9	9.6		12.9		8.7
C-25		7.9	12.5	8.7	12.9		8.7
C-26		10.5	9.6	8.7	12.9		13.0
C-27		13.2	12.5	8.7	12.9		8.7
C-28		10.5	9.6	17.4	6.5		8.7
C-29		7.9	4.8	8.7	6.5		13.0
C-30		7.9	4.8	4.3	12.9		8.7
C-31		10.5	12.5	43.4	6.5		26.1
C-32		7.9	4.8		6.5		4.3
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	CVIII	CIX	CX	CXI	CXII	CXIII	CXIV
C-12	0		0	0	0		
C-13							
C-14							
C-15							
C-16							
C-17		6.3					2.4
C-18							
C-19							3.3
C-20							1.6
C-21		5.3				33.3	1.6
C-22							3.3
C-23							4.9
C-24		5.3					8.2
C-25		10.5					11.5
C-26		12.6					13.1
C-27		14.7				16.7	13.1
C-28		11.6					9.8
C-29		10.5					9.8
C-30		11.6				33.3	6.6
C-31		11.6				16.7	8.2
C-32							2.4
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	CXV	CXVI	CXVII	CXVIII	CXIX	CXX	CVI
C-12							
C-13							
C-14							
C-15	18.2	17.4				2.3	5.8
C-16		2.7				2.3	6.6
C-17	36.5	25.5		4.8	0.8	5.4	9.9
C-18		2.7		0.8	0.8	3.9	6.6
C-19		14.1	0.7	1.6	0.8	3.9	5.8
C-20		2.1	0.3	2.4	1.1	3.1	4.1
C-21		3.5		2.4		20.9	11.9
C-22		3.0	1.6	6.4	3.2	4.7	5.3
C-23		5.4	6.5	6.5	7.5	5.4	4.9
C-24		4.2	10.9	9.6	12.3	7.8	5.3
C-25	4.5	5.7	16.3	16.7	16.5	7.8	11.1
C-26	4.5	4.5	17.4	16.7	16.0	7.8	4.1
C-27	4.5	3.6	14.3	13.3	14.9	6.2	8.2
C-28	9.1	2.7	8.2	10.0	10.7	14.0	0.8
C-29	18.2	1.8	6.5	8.3	5.3	3.1	8.6
C-30	4.5	0.6	2.0	3.3	7.5	1.6	0.8
C-31		0.6	3.1				
C-32			12.3		2.7		
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	CXXII	CXXIII	CXXIV	CXXV	CXXVI	CXXVII	CXXVIII
C-12							
C-13							
C-14							
C-15	13.4				0.3		9.4
C-16	4.5				0.7		1.5
C-17	12.3	2.8	39.9	24.3	2.8	0.8	16.4
C-18	1.8	4.2	1.4	2.3	1.8	0.8	1.9
C-19	3.6	5.6	3.4	3.5	2.5	0.4	3.4
C-20	2.5	4.2	1.7	1.7	3.2	0.8	1.5
C-21	3.4	83.0	2.7	11.6	9.2	6.8	1.5
C-22	3.6		2.4	3.5	5.1	4.7	3.0
C-23	22.8		10.9	6.9	6.2	8.4	6.0
C-24	6.7		3.8	4.6	8.7	12.5	8.5
C-25	7.4		8.5	6.9	11.0	16.3	10.0
C-26	6.7		4.1	4.6	10.1	16.7	10.5
C-27	5.6		7.8	9.2	10.8	13.7	9.0
C-28	3.1		3.1	9.2	9.9	9.9	7.9
C-29	2.2		6.8	6.9	11.3	6.1	4.5
C-30	0.4		1.0	4.6	6.2	2.3	1.9
C-31			2.4				3.0
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 17 (Continued)

Sample	CXXXIX	CXXX	CXXXI	CXXXII	CXXXIII	CXXXIV	CXXXV
C-12							
C-13							
C-14							
C-15	45.1		0.7			0.7	
C-16	1.4		0.3		1.1	0.7	
C-17	14.1		3.1		4.0	2.3	
C-18	1.4	0.3			2.9	2.3	
C-19	1.4	2.1	0.7		2.9	2.3	
C-20		1.0	0.3		2.3	2.3	
C-21	1.4	2.1	7.0	1.0	42.3	15.5	
C-22	1.4	3.4	3.1	2.9	2.9	3.9	2.1
C-23	2.8	9.6	8.4	6.7	6.9	7.0	8.5
C-24	4.2	11.4	14.3	10.5	9.1	9.3	10.6
C-25	7.0	15.5	17.5	16.2	13.7	11.6	14.9
C-26	5.6	17.8	16.4	17.1	12.0	11.6	12.8
C-27	4.2	15.2	12.9	16.2		10.9	14.9
C-28	2.8	10.6	8.0	11.4		10.9	12.8
C-29	4.2	6.5	4.5	13.3		6.3	17.0
C-30	2.8	3.1	2.1	4.8		2.3	6.4
C-31		1.8					
C-32			0.3				
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 18

ADDITIONAL ANALYTICAL DATA FOR FISH SAMPLES

Sample	Total n-Alkane (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	1.28	0.04	2.00	8.26
II	2.18	0	0.50	5.21
III	0.08	2.00	0	--
IV	0.30	0	0	--
V	0.53	2.10	0.67	12.3
VI	1.25	--	1.50	1.50
VII	0.21	1.25	2.27	1.86
VIII	1.25	2.00	0	1.78
IX	1.21	0.38	0.50	16.5
X	111	61.56	1.11	17.5
XI	2.10	0.52	1.00	49.0
XII	1260	0	2.50	142
XIII	0.15	0	1.00	3.98
XIV	1.16	0	0.50	8.71
XV	4.36	0.02	1.00	42.5
XVI	0.60	--	4.00	1.99
XVII	3.73	1.40	0	9.41
XVIII	20.8	1.25	0.50	5.90
XIX	0.49	3.50	0	5.17
XX	1.10	1.60	1.00	5.29
XXI	22.8	0	0	3.07
XXII	0.55	0.40	0.67	3.12
XXIII	0.47	0.83	1.00	2.73
XXIV	1.92	0	0.40	8.17
XXV	2.87	0.30	0.40	2.57
XXVI	0.11	0	1.00	2.66
XXVII	0.16	1.63	2.00	6.75
XXVIII	3.20	0	0	7.06
XXIX	3.79	50.0	0.86	2.97
XXX	545	0	0	1.73
XXXI	0.16	0.67	0.50	2.16
XXXII	15.6	81.6	0	14.6
XXXIII	0.26	0.48	2.50	20.7
XXXIV	0.70	1.33	0	1.92
XXXV	0.13	1.50	1.00	3.35
XXXVI	1.54	1.00	2.00	14.9
XXXVII	0.22	0.50	1.00	0.16
XXXVIII	0.16	1.00	0	0.78
XXXIX	0.18	0	0	5.99
XL	0	--	--	--
XLI	0.14	0	0	2.50
XLII	1.01	0	0	1.80
XLIII	0.09	0	0	7.93
XLIV	0	--	--	--
XLV	0.03	--	--	0.67
XLVI	0.79	0	--	2.28
XLVII	0.67	55.5	0.50	13.9

TABLE 18 (Continued)

Sample	Total n-Alkane (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XLVIII	0.07	1.00	0	1.33
XLIX	0.03	0	0	1.00
L	0.05	0	--	0.83
LI	0.07	--	--	0.73
LII	0.30	1.00	1.00	0.50
LIII	0.84	2.00	4.00	1.00
LIV	0	--	--	--
LV	2.20	--	--	0.33
LVI	0.40	--	76.3	0.60
LVII	1.50	--	0.50	3.15
LVIII	0.05	4.00	1.00	1.50
LIX	0.39	--	2.00	1.05
LX	0.12	2.00	1.00	1.11
LXI	2.55	2.00	1.00	7.40
LXII	0.92	0.75	1.50	2.07
LXIII	1.38	1.00	--	9.00
LXIV	0.88	1.00	--	6.04
LXV	23.7	0	--	1.08
LXVI	3.02	2.0	1.2	2.92
LXVII	16.75	8.0	1.0	1.18
LXVIII	1.67	1.61	0.4	1.93
LXIX	10.75	4.0	--	0.48
LXX	0.57	5.79	2.0	2.08
LXXI	0	--	--	--
LXXII	2.67	24.81	2.5	3.53
LXXIII	10.40	--	--	0.93
LXXIV	0.26	25.63	--	1.83
LXXV	0	--	--	--
LXXVI	0.54	6.1	2.0	1.37
LXXVII	0	--	--	--
LXXVIII	0.65	3.2	2.0	4.42
LXXIX	0	--	--	--
LXXX	0.34	8.0	--	1.04
LXXXI	4.32	12.84	--	0.92
LXXXII	6.4	2.93	--	3.0
LXXXIII	0.92	12.5	--	1.09
LXXXIV	0.61	--	--	0.75
LXXXV	0.59	1.0	--	0.59
LXXXVI	0.70	5.86	0.25	1.32
LXXXVII	52	0.77	1.0	1.67
LXXXVIII	0.51	7.25	0.25	1.35
LXXXIX	9.7	15.38	1.75	1.94
XC	3.1	6.8	--	1.0
XCI	0	--	--	--
XCII	1.63	5.0	--	1.25
XCIII	4.65	6.86	7.0	1.08
XCIV	2.70	8.67	--	2.0
XCV	3.63	--	--	0.96
XCVI	1.54	2.0	--	1.33

TABLE 18 (Continued)

Sample	Total n-Alkane (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XCVII	10.70	--	--	0.57
XCVIII	0.63	10	--	1.42
XCIX	5.0	--	--	0.82
C	1.47	2.22	1.5	2.06
CI	0	--	--	--
CII	1.52	1.33	--	1.24
CIII	0.52	2.0	--	1.6
CIV	13.8	--	--	2.29
CV	5.74	--	--	0.94
CVI	0	--	--	--
CVII	2.3	--	--	1.3
CVIII	0	--	--	--
CIX	0.95	1.33	--	1.44
CX	0	--	--	--
CXI	0	--	--	--
CXII	0	--	--	--
CXIII	0.12	--	--	2.0
CXIV	0.3	6.0	--	1.22
CXV	2.69	6.5	--	4.54
CXVI	1.67	2.0	0.78	3.44
CXVII	8.97	--	--	0.90
CXVIII	0.63	3.0	4.0	1.08
CXIX	3.75	3.3	0.67	0.85
CXX	1.29	2.7	0.7	1.22
CXXI	12.15	1.37	0.44	1.96
CXXII	2.24	3.3	2.0	2.41
CXXIII	0.7	8.0	1.0	10.8
CXXIV	1.47	0.9	0.5	4.75
CXXV	3.46	0.52	--	2.26
CXXVI	2.17	1.67	0.63	1.18
CXXVII	1.32	--	--	1.10
CXXVIII	0.67	2.72	0.54	1.72
CXXIX	7.1	3.6	--	4.07
CXXX	1.94	--	4.0	1.11
CXXXI	5.72	4.67	--	1.22
CXXXII	1.05	--	--	1.14
CXXXIII	0.95	1.43	0.8	2.30
CXXXIV	0.4	4.7	0.7	1.30
CXXXV	0.24	--	--	1.24

TABLE 19

TABULATION OF BENTHIC ORGANISMS

Sample	Date	Location	Species	Collection Method
I	2-16-77	Pfm A	brittle worm (*Chloeia viridis*)	trap
II	3-2-77	Jkt K	sea urchin (*Arbacia unctulata*)	diver
III	7-29-77	JktB	sea urchin (*Arbacia unctulata*)	diver
IV	8-12-77	PfmA	yellow coral (Alcyonaria)	diver
V	8-12-77	PfmA	brown hydroid (Hydroida)	diver
VI	8-12-77	PfmA	Atlantic wing oyster (*Pteria colymbus*)	diver
VII	8-16-77	PfmA	horse conch (*Pleuroploea gigantea*)	diver
VIII	8-16-77	PfmA	brown hydroid (Hydroida)	diver
IX	8-19-77	JktB	Atlantic wing oyster (*Pteria colymbus*)	diver
X	8-19-77	JktB	yellow coral (Alcyonaria)	diver
XI	8-19-77	JktB	giant eastern murex (*Murex fulvescens*)	diver
XII	8-19-77	Flare Stk A	Florida horse conch (*Pleuroploca gigantea*)	diver
XIII	8-19-77	Flare Stk A	giant eastern murex (*Murex fulvescens*)	diver
XIV	8-19-77	Flare Stk A	Hermit crab (*Pagurus floridanus*)	diver
XV	8-19-77	Flare Stk A	Banded tulip shell (*Fasciolaria hunteria*)	diver
XVI	10-19-77	PfmA	Atlantic wing oyster (*Pteria colymbus*)	diver

TABLE 19 (Continued)

Sample	Date	Location	Species	Collection Method
XVII	10-19-77	PfmA	Florida horse conch (*Pleuroploea gigantea*)	diver
XVIII	10-19-77	PfmA	Florida horse conch (*Pleuroploea gigantea*)	diver
XIX	10-27-77	PfmA	yellow coral (Alcyonaria)	diver
XX	10-27-77	PfmA	Atlantic wing oyster (*Pteria colymbus*)	diver
XXI	10-27-77	PfmA	brown hydroid (Hydroida)	diver
XXII	10-27-77	PfmA	Atlantic wing oyster (*Pteria colymbus*)	diver
XXIII	10-27-77	QtrA	yellow coral (Alcyonaria)	diver
XXIV	10-27-77	QtrA	brown hydroid (Hydroida)	diver
XXV	10-27-77	QtrA	Florida horse conch (*Pleuroploea gigantea*)	diver
XXVI	10-28-77	JktB	yellow coral (Alcyonaria)	diver
XXVII	10-28-77	JktB	brown hydroid (Hydroida)	diver
XXVIII	10-28-77	JktB	Florida horse conch (*Pleuroploea gigantea*)	diver
XXIX	2-2-78	PfmB	Florida horse conch (*Pleuroploea gigantea*)	diver
XXX	2-2-78	PfmB	Florida horse conch (*Pleuroploea gigantea*)	diver
XXXI	2-2-78	PfmB	brown hydroid (Hydroida)	diver
XXXII	2-2-78	PfmB	brown hydroid (Hydroida)	diver
XXXIII	2-2-78	PfmB	sea urchin (*Arbacia unctulata*)	diver

TABLE 19 (Continued)

Sample	Date	Location	Species	Collection Method
XXXIV	2-2-78	PfmB	yellow coral (Alcyonaria)	diver
XXXV	2-28-78	PfmB	Atlantic wing oyster (*Pteria colymbus*)	diver
XXXVI	2-28-78	PfmB	Atlantic wing oyster (*Pteria colymbus*)	diver
XXXVII	2-22-78	QtrB	Florida horse conch (*Pleuroploea gigantea*)	diver
XXXVIII	2-28-78	QtrB	Florida horse conch (*Pleuroploea gigantea*)	diver
XXXIX	2-28-78	QtrB	bushy hydroid (Hydroida)	diver
XL	2-28-78	QtrB	brown hydroid (Hydroida)	diver
XLI	2-28-78	QtrB	giant eastern murex (*Murex fulvescens*)	diver
XLII	3-10-78	JktB	Florida horse conch (*Pleuroploea gigantea*)	diver
XLIII	3-10-78	JktB	Florida horse conch (*Pleuroploea gigantea*)	diver
XLIV	3-10-78	JktB	Atlantic wing oyster (*Pteria colymbus*)	diver
XLV	3-10-78	JktB	Atlantic wing oyster (*Pteria colymbus*)	diver
XLVI	3-10-78	JktB	sea urchin (*Arbacia unctulata*)	diver
XLVII	3-10-78	JktB	yellow coral (Alcyonaria)	diver
XLVIII	3-10-78	JktB	giant eastern murex (*Murex fulvescens*)	diver

TABLE 20

DISTRIBUTION OF n-ALKANES IN BENTHIC ORGANISMS

Sample	I	II	III	IV	V	VI	VII	VIII	IX
C-12			0			0			0
C-13									
C-14									
C-15									
C-16		1.5							
C-17	0.5			0.6	0.1				
C-18	0.3	1.5			0.1				
C-19	1.0	20.9			0.1				
C-20	11.0	1.5			0.1				
C-21	64.2	44.8			0.1				
C-22	20.1	1.5		1.2	1.1				
C-23	0.5	1.5		3.9	3.3		13.3		
C-24	0.5	3.0		7.9	6.3		20.0		
C-25	0.5	3.0		13.8	9.0		20.0		
C-26	0.5	3.0		18.1	12.1		26.7	18.2	
C-27	0.5	4.5		17.7	13.9		20.0	18.2	
C-28	0.5	9.0		15.3	15.1			18.2	
C-29		4.5		8.3	14.6			18.2	
C-30				7.1	10.8			18.2	
C-31				3.9	6.9			9.1	
C-32				1.8	3.7				
C-33					1.9				
C-34					0.1				
C-35									
C-36									
C-37									

TABLE 20 (Continued)

Sample	X	XI	XII	XIII	XIV	XV	XVI
C-12		0	0	0	0	0	
C-13							
C-14							
C-15							
C-16							
C-17	1.8						
C-18	1.8						
C-19							
C-20							13.3
C-21							
C-22	1.8						
C-23	5.4						
C-24	8.9						
C-25	17.9						
C-26	16.1						20.0
C-27	14.3						20.0
C-28	12.5						13.3
C-29	8.9						16.7
C-30	5.4						10.0
C-31	5.4						6.7
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 20 (Continued)

Sample	XVII	XVIII	XIX	XX	XXI	XXII	XXIII
C-12	0			0		0	0
C-13							
C-14							
C-15							
C-16							
C-17					6.4		
C-18							
C-19					4.3		
C-20							
C-21					2.1		
C-22		10.9			2.1		
C-23		10.9	4.7		4.3		
C-24		10.9	7.0		6.4		
C-25		10.9	9.3		8.5		
C-26		10.9	11.6		9.6		
C-27		4.3	11.6		10.6		
C-28		4.3	11.6		9.6		
C-29		4.3	10.5		9.6		
C-30		21.7	9.3		7.4		
C-31		10.9	11.6		10.6		
C-32			5.8		4.3		
C-33			4.7		3.2		
C-34			2.3		1.1		
C-35							
C-36							
C-37							

TABLE 20 (Continued)

Sample	XXIV	XXV	XXVI	XXVII	XXVIII	XXIX	XXX
C-12		0			0		
C-13							
C-14							
C-15							
C-16							
C-17			3.9	2.3			
C-18				1.6			
C-19				1.6			
C-20				0.8			
C-21				3.9			
C-22				2.3			
C-23			5.4	3.1			
C-24	4.5		7.7	7.0			8.9
C-25	9.1		11.6	8.5			8.9
C-26	9.1		11.6	11.6		10	13.3
C-27	18.2		9.7	11.6		20	13.3
C-28	27.3		19.3	10.1		20	17.8
C-29	9.1		7.7	8.5		30	13.3
C-30	9.1		7.7	9.3		20	17.8
C-31	9.1		11.6	10.9			6.7
C-32	4.5		3.9	3.9			
C-33				3.1			
C-34							
C-35							
C-36							
C-37							

TABLE 20 (Continued)

Sample	XXXI	XXXII	XXXIII	XXXIV	XXXV	XXXVI	XXXVII
C-12						0	
C-13							
C-14							
C-15							
C-16							
C-17				0.3			
C-18			37.8	0.9			
C-19			9.2	2.3			
C-20			6.3	1.1			
C-21				4.3	36.9		
C-22	2.4	1.9	25.2	2.9			
C-23	3.8	3.1		5.7	2.4		
C-24	6.6	6.2	7.1	7.4	5.9		9.3
C-25	10.9	9.9		13.5	8.3		9.3
C-26	13.3	11.7	4.2	15.5	10.7		14.0
C-27	15.2	14.8		14.6	9.5		
C-28	12.3	12.3	10.1	11.5	14.3		18.6
C-29	13.3	15.4		9.5	7.1		14.0
C-30	10.4	11.1		5.4	4.8		18.6
C-31	9.5	9.9		3.7			7.0
C-32	2.4	3.7		1.4			4.7
C-33							4.7
C-34							
C-35							
C-36							
C-37							

TABLE 20 (Continued)

Sample	XXXVIII	XXXIX	XL	XLI	XLII	XLIII	XLIV
C-12				0	0		
C-13							
C-14							
C-15							
C-16							
C-17						61.1	2.6
C-18						6.4	0.7
C-19						0.6	2.2
C-20			0.2			0.5	0.7
C-21			3.1			20.4	65.6
C-22	0.4		1.9			0.4	0.9
C-23	3.2	2.3	5.8			5.0	1.8
C-24	9.1	5.8	10.7			1.1	2.2
C-25	16.2	11.6	15.5			1.7	4.0
C-26	20.5	16.3	17.5			0.3	2.9
C-27	20.0	18.6	15.9			0.4	2.2
C-28	14.2	15.1	11.6			1.1	2.2
C-29	8.8	14.0	8.7			0.3	1.1
C-30	4.7	9.3	5.1			0.3	1.1
C-31	2.8	5.8	2.9			0.5	9.8
C-32		1.2	1.0				
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 20 (Continued)

Sample	XLV	XLVI	XLVII	XLVIII
C-12				0
C-13				
C-14				
C-15				
C-16				
C-17		0.6		
C-18	0.3	0.3	1.7	
C-19	0.2	0.6		
C-20	0.4	2.5	0.3	
C-21	2.7	29.7	2.0	
C-22	0.6	3.8	2.7	
C-23	0.6	0.9	6.4	
C-24	1.1	5.1	10.7	
C-25	4.1	1.9	15.4	
C-26	11.8	6.3	16.7	
C-27	44.0	3.8	15.1	
C-28	19.2	34.1	11.0	
C-29	8.1	4.4	7.4	
C-30	1.8	3.2	5.4	
C-31	5.2	2.5	3.0	
C-32			1.0	
C-33			1.3	
C-34				
C-35				
C-36				
C-37				

TABLE 21

ADDITIONAL ANALYTICAL DATA FOR BENTHIC SAMPLES

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	998	0	0	2.05
II	670	--	0.50	3.76
III	0	--	--	--
IV	5090	4.67	--	0.93
V	34825	14.0	--	1.00
VI	0	--	--	--
VII	195	--	--	1.1
VIII	1100	--	--	0.83
IX	0	--	--	--
X	5600	7.0	1.0	1.15
XI	0	--	--	--
XII	0	--	--	--
XIII	0	--	--	--
XIV	0	--	--	--
XV	0	--	--	--
XVI	150	--	--	1.31
XVII	0	--	--	--
XVIII	2300	--	--	0.70
XIX	430	--	--	1.10
XX	0	--	--	--
XXI	940	3.5	--	1.47
XXII	0	--	--	--
XXIII	0	--	--	--
XXIV	6710	--	--	0.83
XXV	0	--	--	--
XXVI	2590	5.0	--	0.99
XXVII	12900	6.0	1.0	1.15
XXVIII	0	--	--	--
XXIX	100	--	--	1.0
XXX	225	--	--	0.73
XXXI	4220	--	--	1.11
XXXII	4860	--	--	1.13
XXXIII	2380	--	--	0.10
XXXIV	3490	5.0	0.67	1.17
XXXV	420	--	--	1.8
XXXVI	0	--	--	--
XXXVII	215	--	--	1.05
XXXVIII	4640	--	--	1.04
XXXIX	3440	--	--	1.10
XL	10305	--	--	1.08
XLI	0	--	--	--
XLII	0	--	--	--
XLIII	7850	0.8	--	8.94
XLIV	2745	2.29	1.0	8.31
XLV	2704	--	0.71	1.84
XLVI	1580	2.0	10.0	0.81
XLVII	2990	--	--	1.02
XLVIII	0	--	--	--

TABLE 22

TABULATION OF SEDIMENT SAMPLES

Sample	Date	Location	Collection Method
I	6-5-76	21	core
II	6-5-76	31	core
III	6-5-76	104	core
IV	6-5-76	105	core
V	6-5-76	105	grab
VI	6-5-76	107	core
VII	6-5-76	108	core
VIII	6-10-76	11	core
IX	6-10-76	13	core
X	6-10-76	40	core
XI	6-10-76	62	core
XII	6-10-76	69	core
XIII	6-10-76	70	core
XIV	6-10-76	96	core
XV	6-10-76	97	core
XVI	6-10-76	98	grab
XVII	6-10-76	99	core
XVIII	6-10-76	100	core
XIX	6-11-76	32	core
XX	6-11-76	61	core
XXI	6-11-76	63	core
XXII	6-11-76	67	core
XXIII	6-11-76	71	core
XXIV	6-11-76	73	core
XXV	6-11-76	74	core
XXVI	6-11-76	76	core
XXVII	6-11-76	77	core
XXVIII	6-11-76	78	core
XXVIX	6-11-76	80	core
XXX	6-11-76	81	core
XXXI	6-11-76	82	core
XXXII	6-11-76	83	grab
XXXIII	6-11-76	84	core
XXXIV	6-11-76	85	core
XXXV	6-11-76	92	core
XXXVI	6-11-76	101	core
XXXVII	6-11-76	102	core
XXXVIII	6-11-76	110	core
XXXIX	6-12-76	38	core
XL	6-12-76	39	core
XLI	6-12-76	86	core
XLII	6-12-76	87	grab
XLIII	6-12-76	89	grab
XLIV	6-12-76	91	grab
XLV	6-12-76	94	core
XLVI	7-1-76	6	core
XLVII	7-1-76	17	core
XLVIII	7-2-76	18	core

TABLE 22 (Continued)

Sample	Date	Location	Collection Method
XLIX	12-17-76	PfmB - NE	diver
L	12-17-76	PfmB - NE (8m)	diver
LI	12-17-76	PfmB - NE (16.5m)	diver
LII	12-17-76	PfmB - NE (25m)	diver
LIII	12-17-76	PfmB - SE	diver
LIV	12-17-76	PfmB - SE (8m)	diver
LV	12-17-76	PfmB - SE (16.5m)	diver
LVI	12-17-76	PfmB - SE (25m)	diver
LVII	12-17-76	PfmB - NW	diver
LVIII	12-17-76	PfmB - NW (8m)	diver
LIX	12-17-76	PfmB - NW (16.5m)	diver
LX	12-17-76	PfmB - NW (25m)	diver
LXI	12-17-76	PfmB - SW	diver
LXII	12-17-76	PfmB - center	diver
LXIII	12-17-76	PfmA - NE	diver
LXIV	12-17-76	PfmA - NE (8m)	diver
LXV	12-17-76	PfmA - NE (16.5m)	diver
LXVI	12-17-76	PfmA - NE (25m)	diver
LXVII	12-17-76	PfmA - SE	diver
LXVIII	12-17-76	PfmA - SE (8m)	diver
LXIX	12-17-76	PfmA - SE (16.5m)	diver
LXX	12-17-76	PfmA - SE (25m)	diver
LXXI	12-17-76	PfmA - NW	diver
LXXII	12-17-76	PfmA - NW (8m)	diver
LXXIII	12-17-76	PfmA - NW (16.5m)	diver
LXXIV	12-17-76	PfmA - NW (25m)	diver
LXXV	12-17-76	PfmA - SW	diver
LXXVI	12-17-76	PfmA - center	diver
LXXVII	10-5-77	PfmA - center	diver
LXXVIII	10-5-77	PfmA - E (8m)	diver
LXXIX	10-5-77	PfmA - E (16.5m)	diver
LXXX	10-5-77	PfmA - E (25m)	diver
LXXXI	10-5-77	PfmA - E (33m)	diver
LXXXII	10-28-77	PfmA - E (50m)	diver
LXXXIII	10-28-77	PfmA - E (100m)	diver
LXXXIV	10-28-77	PfmA - E (200m)	diver
LXXXV	10-5-77	PfmA - W (8m)	diver
LXXXVI	10-6-77	PfmA - W (16.5m)	diver
LXXXVII	10-6-77	PfmA - W (25m)	diver
LXXXVIII	10-6-77	PfmA - W (33m)	diver
LXXXIX	10-28-77	PfmA - W (50m)	diver
XC	10-28-77	PfmA - W (100m)	diver
XCI	10-28-77	PfmA - W (200m)	diver
XCII	10-6-77	JktB (center)	diver
XCIII	10-6-77	JktB - E (8m)	diver
XCIV	10-6-77	JktB - E (16.5m)	diver
XCV	10-6-77	JktB - E (25m)	diver
XCVI	10-6-77	JktB - E (33m)	diver
XCVII	10-28-77	JktB - E (50m)	diver
XCVIII	10-28-77	JktB - E (100m)	diver

TABLE 22 (Continued)

Sample	Date	Location	Collection Method
XCIX	10-28-77	JktB - E (200m)	diver
C	10-7-77	JktB - W (8m)	diver
CI	10-7-77	JktB - W (16.5m)	diver
CII	10-7-77	JktB - W (25m)	diver
CIII	10-7-77	JktB - W (33m)	diver
CIV	10-28-77	JktB - W (50m)	diver
CV	10-28-77	JktB - W (100m)	diver
CVI	10-28-77	JktB - W (200m)	diver

TABLE 23

DISTRIBUTION OF n-ALKANES IN SEDIMENT SAMPLES

Sample	I	II	III	IV	V	VI	VII
C-12	2.2		2.3	4.3			
C-13	0.4		6.0				
C-14	17.7		2.7	17.6		1.0	0.1
C-15	3.0	2.8	1.7	2.6		5.0	0.3
C-16	0.7	2.8	0.6	2.6		5.0	0.7
C-17	5.6	6.1	1.4	6.4		10.1	
C-18	0.6	2.8	0.5	1.3		3.0	0.2
C-19		2.2	0.1	1.0		3.0	0.1
C-20	5.8	1.1				1.5	
C-21	0.3	9.4	0.5	6.1		17.1	1.0
C-22	1.4	1.1	0.4	0.8		1.0	0.3
C-23	1.7	2.8	1.1	1.3		2.0	0.9
C-24	4.6	1.1	2.4	1.5		1.0	3.2
C-25	6.1	5.0	6.5	4.1		5.0	8.2
C-26	8.9	3.3	7.8	4.1		4.0	12.2
C-27	7.1	8.3	12.2	7.4		7.0	14.7
C-28	11.0	4.4	10.4	5.1		1.0	13.6
C-29	4.8	15.0	13.6	10.1		16.1	13.6
C-30	8.9	2.2	8.0	2.8		3.0	9.9
C-31	3.2	16.7	10.7	10.5		13.1	9.6
C-32	3.9	2.8	3.7	2.8		1.0	4.6
C-33	0.9	10.0	4.9	6.4			4.0
C-34	1.3		1.2				1.6
C-35			1.3	1.3			1.3
C-36							
C-37							

TABLE 23 (Continued)

Sample	VIII	IX	X	XI	XII	XIII	XIV
C-12	12.9	16.7	0.3	5.8	5.3		
C-13	3.5	3.5	0.5	7.5			
C-14		0.4	0.3	1.7		0.6	
C-15	5.8	3.5	1.7	4.2	2.3	4.8	7.2
C-16	2.3	1.8	1.7	4.2	1.6	2.4	5.2
C-17	20.0	28.6	3.5	20.8	17.8	10.7	10.3
C-18	4.7	1.8	2.4	4.2	1.6	3.6	3.1
C-19	7.0	4.4	1.0	16.7	5.4	6.0	5.2
C-20			0.3				
C-21	5.8	4.4	7.3	8.3	2.3	2.4	
C-22		0.4	0.3			0.6	
C-23			1.0			1.2	
C-24	1.2	0.9	2.4		2.3	2.4	
C-25	4.7	3.5	7.0	3.3	7.0	4.8	5.2
C-26	2.3	2.6	8.4	2.5	9.3	3.6	3.1
C-27	7.0	6.7	11.8	5.0	14.7	7.1	7.2
C-28	2.3		9.1	1.7	6.2	2.4	4.1
C-29	1.2	7.9	13.2	5.8	10.1	11.9	10.3
C-30			5.6		5.4	7.1	3.1
C-31	9.4	7.9	10.1	5.8	7.8	9.5	10.3
C-32	2.3		3.5		1.6	9.5	
C-33	3.5	2.6	5.9	2.5	2.3	6.0	3.1
C-34	1.2	0.4	0.7			1.2	
C-35	2.9	1.8	1.7			2.4	3.1
C-36		0.4					
C-37							

TABLE 23 (Continued)

Sample	XV	XVI	XVII	XVIII	XIX	XX	XXI
C-12					11.2		11.1
C-13				3.4	6.9		3.7
C-14				0.7	1.7		
C-15				4.0	4.3		1.8
C-16			4.3	2.7	4.3		1.8
C-17	33.3	40.0	32.2	20.1	19.8	25.8	14.8
C-18	33.3	13.3	6.1	5.4	4.3	25.8	3.0
C-19			8.7	4.0	17.2	6.5	5.0
C-20		6.7	2.6				
C-21			8.7	5.4	3.4	6.5	
C-22	33.3		2.6	0.7		6.5	
C-23			2.6	1.3			
C-24			2.6	1.3		12.9	1.8
C-26			2.6	4.0	1.7		8.9
C-27			6.1	8.7	4.3		14.8
C-28		6.7	11.3	1.3	8.6		11.1
C-29		26.7		0.7	9.5		3.7
C-30		6.7		6.7		16.1	
C-31				12.1			3.7
C-32			5.2	2.7			3.7
C-33				5.4			3.7
C-34				0.7			
C-35				3.4			
C-36							
C-37							

TABLE 23 (Continued)

Sample	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
C-12	22.9						1.1
C-13	2.8						5.6
C-14	0.7			0.3			0.6
C-15	2.8	5.7		2.6			3.9
C-16	1.7	5.7		3.9			3.4
C-17	11.1	30.0		6.5			15.7
C-18	1.4	5.7		3.9			4.5
C-19	9.7	5.7		2.6			2.8
C-20				0.3			2.2
C-21	3.5	7.1	2.8	10.4	7.8	1.8	4.5
C-22	0.7	1.4	1.9	1.0		2.9	1.1
C-23			2.8	1.6		4.2	2.2
C-24	1.0	1.4	4.8	1.6	1.9	5.9	1.7
C-25	2.8	8.6	7.6	5.2	7.8	10.7	5.6
C-26	2.1	7.1	8.5	5.5	5.6	9.4	3.4
C-27	5.6	11.4	10.4	9.1	11.1	11.3	7.9
C-28	2.1		11.3	8.1	9.4	10.1	1.1
C-29	8.3	2.9	10.4	11.7	13.0	10.7	12.4
C-30			7.6	4.5	3.3	6.5	
C-31	7.6	2.9	10.4	10.4	14.8	10.7	9.0
C-32	3.5	1.4	8.5	5.8	9.4	5.9	3.4
C-33	3.5	2.9	8.7	4.5	9.4	5.9	4.5
C-34	0.7		3.7	0.6	3.3	2.3	
C-35	5.6		2.8		3.3	1.8	3.4
C-36			0.9				
C-37							

TABLE 23 (Continued)

Sample	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV
C-12		7.8					
C-13		2.2					
C-14		0.5				1.3	
C-15		1.9			5.1	5.4	
C-16		1.2			14.3	6.7	
C-17		7.6			20.4	37.6	19.0
C-18		1.5			14.3	4.0	19.0
C-19		1.7			5.1	12.1	
C-20	2.5					0.7	4.8
C-21	24.1	2.4	14.1	20.5		6.7	9.5
C-22	2.5				2.0	0.7	4.8
C-23	2.5				2.0		
C-24	2.5	3.2	3.3		2.0	1.3	
C-25	5.8	10.3	3.3	7.7	14.3	6.7	
C-26	3.3	13.2	3.3	2.6	2.6	4.0	
C-27	11.6	13.7	14.1	15.4	2.6	8.1	
C-28	12.5	14.3	14.1	15.4	10.2		9.5
C-29	7.5	8.4	6.7	10.3	2.6	2.7	19.0
C-30	2.5	3.9	6.7	2.6	2.6		9.5
C-31	10.0	3.9	14.1	12.8		2.0	4.8
C-32	7.5		6.7	7.7			
C-33	5.1	1.3	6.7	5.1			
C-34		0.3	3.3				
C-35		0.8	3.3				
C-36							
C-37							

TABLE 23 (Continued)

Sample	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
C-12	34.9		15.6				3.7
C-13	1.6		5.2	4.3	6.0	0.9	1.4
C-14	0.8		0.6		2.0		18.2
C-15	3.2	2.4	4.5	4.3	10.0	1.5	3.7
C-16	4.0	3.1	5.2	2.9	10.0	1.5	2.0
C-17	19.0	26.8	18.2	8.6	16.0	6.1	6.4
C-18	3.2	9.4	5.2	2.9	4.0	1.5	1.1
C-19	6.3	0.8	6.5	2.9	8.0		0.4
C-20							
C-21	4.8	4.7	3.9	15.7		7.6	6.7
C-22			0.6	1.4			0.7
C-23				1.4		1.5	1.2
C-24	0.8	0.8	1.3	1.4		1.5	1.6
C-25	4.0	3.1	3.9	5.7	4.0	6.1	3.9
C-26	3.2	3.9	2.6	4.3	20.0	9.1	4.2
C-27	4.0	7.9	6.5	5.7	8.0	12.2	7.1
C-28	4.0			7.1	6.0	12.2	5.5
C-29	6.3	19.7	6.5	8.6	8.0	12.2	9.3
C-30				1.4		4.6	3.9
C-31		15.7	7.8	8.6	8.0	9.1	8.2
C-32				4.3	4.0	4.6	2.7
C-33		1.6	2.6	4.3	4.0	3.0	5.0
C-34				2.9		1.5	0.9
C-35			3.2	1.4		1.5	1.8
C-36						1.5	
C-37							

TABLE 23 (Continued)

Sample	XLIX	L	LI	LII	LIII	LIV	LV
C-12							
C-13							
C-14	1.5	0.8	1.1	1.4	0.9		
C-15	3.5	2.3	5.5	5.6	2.9		1.3
C-16	5.3	6.0	9.9	8.4	5.1		4.3
C-17	8.2	9.1	17.6	9.8	8.7	6.9	7.8
C-18	7.1	9.1	14.3	12.6	8.7	6.9	7.3
C-19	8.2	10.6	15.4	12.6	11.6	6.9	9.5
C-20	12.4	12.1	11.0	11.2	7.3	6.9	6.0
C-21	9.4	10.6	7.7	11.2	10.9	6.9	9.5
C-22	4.7	7.5	4.4	3.5	8.4	6.9	6.0
C-23	3.5	7.5	2.2	2.8	6.5		4.7
C-24	2.9	6.0	2.2	2.8	2.9	3.4	5.6
C-25	4.7	9.1	3.3	4.2	2.9	6.9	6.9
C-26	3.5	3.8	2.2	5.6	2.9	6.9	3.4
C-27	1.5	3.0	1.1	2.8	1.8	10.4	2.2
C-28	21.8	1.5	0.5	1.4	17.1	10.4	24.6
C-29	1.8	0.8	0.5	1.4	1.1	6.9	0.9
C-30		--	1.1	1.4	0.4		
C-31		0.4		1.4			
C-32							
C-33							
C-34						6.9	
C-35							
C-36						6.9	
C-37							

TABLE 23 (Continued)

Sample	LVI	LVII	LVIII	LIX	LX	LXI	LXII
C-12				5.6		0.7	1.4
C-13		2.4		1.7		2.1	4.2
C-14	0.8	4.9	1.1	1.7		4.6	5.6
C-15	6.2	7.9	4.4	4.9		8.8	12.6
C-16	12.4	9.8	7.7	9.0		12.4	14.7
C-17	18.5	12.4	12.0	12.9	20.0	15.5	16.1
C-18	12.4	11.7	6.6	7.3	9.9	14.2	13.3
C-19	9.3	16.7	5.5	5.6	9.9	14.9	13.3
C-20	3.9	12.0	1.1	1.0	20.0	11.9	11.9
C-21	4.6	9.2	3.3	3.9	20.0	7.8	4.9
C-22	4.6	6.1	1.5	3.9	20.0	3.6	0.7
C-23	1.5	3.6	2.2	3.9		2.3	1.4
C-24	0.8	1.8	1.1	4.4		0.6	
C-25	0.8	1.2	4.4	6.3		0.4	
C-26	0.8	0.3	3.3	6.3		0.1	
C-27	2.3		3.3	7.3			
C-28	12.4		41.6	5.6			
C-29	3.1		0.5	6.3			
C-30	2.3			1.7			
C-31	2.3		0.5	1.0			
C-32	0.8						
C-33	0.4						
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	LXIII	LXIV	LXV	LXVI	LXVII	LXVIII	LXIX
C-12	2.8	4.5	4.2	0.3			3.6
C-13	4.9		2.4	1.6			4.9
C-14	9.5	6.7	4.2	3.3	0.6	2.1	8.4
C-15	11.8	11.2	9.2	6.5	2.9	3.8	11.2
C-16	14.1	13.5	14.2	9.3	4.9	7.7	10.8
C-17	14.1	18.0	15.8	13.6	8.2	13.0	9.8
C-18	10.6	11.2	12.6	14.2	9.1	13.0	8.8
C-19	9.6	11.2	11.0	16.4	7.8	15.3	10.9
C-20	6.1	6.7	7.1	10.9	15.7	13.8	9.9
C-21	4.7	6.7	4.7	6.5	14.4	11.5	8.1
C-22	4.0	3.4	3.7	3.3	10.3	8.4	5.6
C-23	2.4	2.2	2.6	2.2	9.5	5.4	3.5
C-24	1.6	2.2	1.8	2.2	7.4	3.1	1.8
C-25	1.4	2.2	1.3	1.6	6.2	1.5	0.8
C-26	0.5		0.5	0.8	2.1	0.8	0.3
C-27	0.2		0.4	0.8	0.8	0.4	0.3
C-28	0.4		2.4	4.9		0.8	1.4
C-29	0.9		1.0	1.3		0.4	
C-30	0.2			0.3			
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	LXX	LXXI	LXXII	LXXIII	LXXIV	LXXV	LXXVI
C-12		3.0	1.4		5.5	5.5	2.4
C-13					1.8	4.5	4.2
C-14	0.5	3.6	5.7	4.4	7.4	4.9	6.6
C-15	3.3	6.0	9.6	8.8	4.6	6.1	10.2
C-16	6.6	7.6	11.3	11.7	6.6	6.5	12.6
C-17	10.7	9.0	11.6	14.7	11.1	8.2	15.0
C-18	10.7	9.0	11.0	11.7	9.2	9.2	12.6
C-19	13.1	14.0	14.2	14.7	9.2	12.7	13.2
C-20	11.5	14.2	12.0	10.3	7.4	11.8	10.8
C-21	9.8	12.0	9.4	8.8	7.4	10.0	6.6
C-22	8.2	8.0	5.9	5.9	6.6	7.7	3.0
C-23	5.7	6.2	3.7	2.9	3.7	5.6	1.8
C-24	4.1	3.4	1.9	1.5	2.8	3.4	0.6
C-25	3.3	2.0	1.0	0.6	2.2	2.4	0.3
C-26	1.6	1.0	0.4	0.6	0.9	0.9	
C-27	1.1	5.0	0.1	1.5	1.8	0.3	
C-28	8.2	4.0	0.7	1.5	9.2	0.3	
C-29	0.8	2.0		0.6	1.8		
C-30	0.8				0.9	0.1	
C-31							
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	LXXVII	LXXVIII	LXXIX	LXXX	LXXXI	LXXXII	LXXXIII
C-12							
C-13							
C-14							
C-15							
C-16						0.3	
C-17	2.1	0.1				0.5	
C-18	2.7	0.2				0.8	
C-19	2.7	0.4	4.9		3.5	1.1	
C-20		0.4					
C-21	2.7	1.5	9.8	0.7	1.8	2.2	1.9
C-22	4.8	4.7	9.8	2.6	3.5	4.0	2.8
C-23	7.5	9.9	9.8	6.6	7.0	7.0	7.5
C-24	11.8	14.4	9.8	11.8	10.5	11.9	12.3
C-25	15.0	15.9	14.6	15.8	17.5	15.7	16.0
C-26	16.0	16.0	14.6	19.1	17.5	18.6	19.8
C-27	12.3	13.4	9.8	16.5	14.0	15.1	17.0
C-28	12.3	10.6	9.8	12.9	14.0	11.3	11.3
C-29	5.3	7.1	4.9	7.7	7.0	6.7	6.6
C-30	3.7	3.6	2.4	4.0	3.5	3.0	2.8
C-31	1.1	1.4		1.5		1.3	1.9
C-32		0.4		0.7		0.4	
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	LXXXIV	LXXXV	LXXXVI	LXXXVII	LXXXVIII	LXXXIX	XC
C-12					0		
C-13							
C-14			3.1			6.0	
C-15		4.0	0.8	4.5		8.3	
C-16		6.5	3.1	13.4			
C-17		8.5		17.9		7.5	
C-18	0.4	10.1	0.8	1.5		15.8	
C-19	0.4	11.5	3.1	53.7		16.5	
C-20		14.2	9.4			9.0	1.9
C-21	1.4	12.3	7.8	1.5		5.3	1.9
C-22	3.5	10.2	7.8	1.5		4.5	3.7
C-23	7.1	8.0	7.8	6.0		2.3	7.4
C-24	12.4	5.3	10.9			3.0	7.4
C-25	16.3	4.0	9.4			3.8	11.1
C-26	19.4	2.6	9.4			3.8	14.8
C-27	16.6	1.4	7.8			3.8	14.8
C-28	11.7	1.2	6.3			2.3	11.1
C-29	7.1	0.3	7.8			5.3	18.5
C-30	2.5		4.7			3.0	3.7
C-31	1.1						3.7
C-32	0.4						
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	XCI	XCII	XCIII	XCIV	XCV	XCVI	XCVII
C-12		0			0	0	
C-13							
C-14	10.8						
C-15	16.6						
C-16	12.5						
C-17	9.6						
C-18	7.4						
C-19	6.2						
C-20	5.3						
C-21	4.4						1.3
C-22	4.4			1.6			2.7
C-23	4.4		4.8	6.6			5.3
C-24	4.4		9.5	9.8			10.7
C-25	4.4		19.0	13.1			13.3
C-26	3.5		19.0	13.1			16.0
C-27	2.4		9.5	13.1			13.3
C-28	1.7		19.0	13.1			13.3
C-29	1.2		9.5	13.1			10.7
C-30	0.6		4.8	9.8			8.0
C-31	0.1		4.8	6.6			5.3
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	XCVIII	XCIX	C	CI	CII	CIII	CIV
C-12							0
C-13							
C-14							
C-15							
C-16							
C-17							
C-18		4.3					
C-19		1.1					
C-20							
C-21	7.5	8.6			1.1		
C-22	1.9	2.2			2.7	4.8	
C-23	3.8	4.3	7.1	14.3	5.7	9.5	
C-24	7.5	6.5	7.1	14.3	10.3	9.5	
C-25	7.5	10.8	14.3	14.3	13.3	9.5	
C-26	11.3	12.9	14.3	14.3	16.0	9.5	
C-27	15.1	15.1	14.3	14.3	15.3	14.3	
C-28	11.3	12.9	14.3	14.3	14.1	14.3	
C-29	18.9	12.9	14.3	14.3	10.3	14.3	
C-30	7.5	4.3	7.1		6.5	4.8	
C-31	7.5	4.3	7.1		4.6	9.5	
C-32							
C-33							
C-34							
C-35							
C-36							
C-37							

TABLE 23 (Continued)

Sample	CV	CVI
C-12		0
C-13		
C-14		
C-15		
C-16		
C-17		
C-18		
C-19		
C-20	0.2	
C-21	0.5	
C-22	2.2	
C-23	5.3	
C-24	9.7	
C-25	13.0	
C-26	15.7	
C-27	15.3	
C-28	13.9	
C-29	10.8	
C-30	7.2	
C-31	3.6	
C-32	1.8	
C-33	0.6	
C-34	0.2	
C-35		
C-36		
C-37		

TABLE 24

ADDITIONAL ANALYTICAL DATA FOR SEDIMENT SAMPLES

Sample	Total n-Alkanes (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	583	--	--	1.21
II	360	1.27	0.5	3.49
III	830	--	--	1.51
IV	0	--	--	--
V	392	--	--	1.33
VI	398	1.5	--	3.80
VII	3023	--	--	1.16
VIII	86	--	4	2.42
IX	114	--	--	2.94
X	861	1.7	--	1.84
XI	120	--	0.8	3.98
XII	129	--	--	2.30
XIII	84	--	--	2.00
XIV	97	1.2	--	4.38
XV	30	--	--	0.50
XVI	37.5	--	--	2.00
XVII	115	--	--	1.68
XVIII	75	0.12	--	2.82
XIX	116	--	--	2.14
XX	155	1.5	--	0.63
XXI	136	--	--	1.42
XXII	144	--	--	1.72
XXIII	140	--	--	3.41
XXIV	118	--	--	1.18
XXV	155	1.3	0.25	1.82
XXVI	64	--	--	2.04
XXVII	154	--	--	1.33
XXVIII	77	--	--	2.22
XXIX	67	--	--	2.00
XXX	593	--	--	1.18
XXXI	90	--	--	1.21
XXXII	78	--	--	2.54
XXXIII	980	1.0	--	1.08
XXXIV	75	--	--	4.35
XXXV	210	--	--	1.10
XXXVI	3150	--	--	0.96
XXXVII	254	--	--	4.81
XXXVIII	89	--	--	3.44
XXXIX	140	1.25	--	2.50
XL	125	1.5	--	1.17
XLI	328	--	--	1.63
XLII	562	--	--	1.23
XLIII	76	--	--	1.93
XLIV	117	1.25	--	2.60
XLV	2140	1.4	--	1.18
XLIX	0.85	1.0	0.58	0.69

TABLE 24 (Continued)

Sample	Total n-Alkanes (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
L	0.66	1.0	0.50	1.14
LI	0.46	0.94	0.62	1.14
LII	0.14	2.86	0.56	1.07
LIII	1.38	0.96	0.46	1.27
LIV	1.38	0.49	1.0	0.81
LV	1.16	1.0	0.47	0.74
LVI	0.65	0.83	0.63	0.96
LVII	3.30	0.90	0.42	1.15
LVIII	0.46	1.04	0.67	0.57
LIX	0.41	0.94	0.57	1.16
LX	0.47	1.0	1.0	1.0
LXI	7.03	0.89	0.46	1.08
LXII	14.3	0.96	0.58	1.10
LXIII	8.5	1.25	0.51	1.0
LXIV	0.45	1.13	0.40	1.07
LXV	1.91	0.72	0.40	0.98
LXVI	0.92	0.8	0.46	1.02
LXVII	2.4	0.85	0.45	1.00
LXVIII	1.31	0.82	0.35	1.05
LXIX	3.58	0.99	0.32	0.98
LXX	0.61	0.92	0.38	0.92
LXXI	10.01	1.11	0.49	1.00
LXXII	4.57	1.19	0.46	0.99
LXXIII	0.34	1.10	0.50	1.10
LXXIV	0.54	1.08	0.4	0.78
LXXV	9.80	1.00	0.5	0.99
LXXVI	21.65	1.08	--	1.06
LXXVII	0.19	1.0	0.6	0.95
LXXVIII	3.4	1.0	0.5	0.99
LXXIX	0.21	--	--	1.16
LXXX	0.27	--	--	0.96
LXXXI	0.29	--	--	1.04
LXXXII	0.37	1.0	3.0	0.99
LXXXIII	0.11	--	--	1.04
LXXXIV	0.28	--	--	0.99
LXXXV	5.89	0.80	0.47	1.0
LXXXVI	4.16	--	14.22	0.8
LXXXVII	0.34	1.7	--	5.09
LXXXVIII	0	--	--	--
LXXXIX	0.13	1.2	0.48	1.11
XC	0.27	--	--	1.35
XCI	3.61	1.19	0.40	0.98
XCII	0	--	--	--
XCIII	0.05	--	--	0.91
XCIV	0.15	--	--	1.11
XCV	0	--	--	--
XCVI	0	--	--	--
XCVII	0.04	--	--	0.97

TABLE 24 (Continued)

Sample	Total n-Alkanes (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
XCVIII	0.03	--	--	1.52
XCIX	0.47	--	--	1.32
C	0.01	--	--	1.33
CI	0.01	--	--	1.33
CII	0.26	--	--	1.02
CIII	0.01	--	--	1.33
CIV	0	--	--	--
CV	1.11	--	--	0.97
CVI	0	--	--	--

TABLE 25

TABULATION OF MISCELLANEOUS SAMPLES

Sample	Date	Platform	Description
I	10-3-76	Gus III	Vessel Fuel
II	6-26-77	B	Skim Tank Oil
III	6-26-77	B	Brine Separator Drip Pan Water
IV	6-26-77	B	Biocide K31
V	6-26-77	B	Biocide KC14
VI	6-26-77	B	Surfactron DQ44
VII	9-18-77	-	Net Dip Solution
VIII	10-23-77	A	Nepheloid Layer (15m)
IX	10-23-77	A (30m South)	Nepheloid Layer (15m)
X	2-26-78	Qtr B	Sewage Pipe Discharge Water

TABLE 26

DISTRIBUTION OF n-ALKANES IN MISCELLANEOUS SAMPLES

Sample	I	II	III	IV	V	VI	VII	VIII	IX	X
C-12								0	0	
C-13	5.4									
C-14	2.7		3.1							
C-15	4.5	17.4	4.5	29.1						6.0
C-16	3.6	16.0	3.7	5.3						24.7
C-17	30.4	16.0	5.4	5.3	1.6		1.8			11.0
C-18	21.4	13.1	6.5	3.7	1.6					19.5
C-19	16.1	7.3	7.1	3.7	1.6		3.7			6.6
C-20	8.9	6.8		1.1	2.5	1.5	6.6			10.6
C-21	4.4	5.7	4.0	2.1	4.4	1.5	1.8			2.3
C-22	1.9	4.6	4.8	3.7	6.3	3.1	1.8			1.3
C-23	0.4	3.8	5.9	3.7	6.3	4.6	3.3			1.3
C-24	0.2	2.9	7.9	3.7	6.3	6.7	5.9			1.3
C-25	0.2	2.4	9.9	5.3	6.3	9.2	9.2			1.9
C-26		1.7	10.2	6.3	6.3	10.7	11.0			1.9
C-27		1.2	9.3	6.3	12.5	16.9	11.8			2.1
C-28		0.7	7.6	13.2	13.8	12.3	11.0			1.7
C-29		0.4	5.7	3.7	15.7	17.5	10.3			2.3
C-30		0.1	2.8	2.6	4.4	9.8	12.9			1.3
C-31		0.04	1.4	1.1	6.3	6.1	5.5			2.7
C-32					4.4		2.2			0.6
C-33							1.1			0.6
C-34										
C-35										
C-36										
C-37										

TABLE 27

ADDITIONAL ANALYTICAL DATA FOR MISCELLANEOUS SAMPLES

Sample	Total n-Alkanes	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	12.3 %	0.62	0.42	1.58
II	13.77%	0.78	0.3	1.18
III	35.3 ppb	1.0	2.56	1.14
IV	1.89 ppm	1.0	0.71	1.52
V	1.60 ppm	1.6	1.0	1.2
VI	3.26 ppm	--	--	1.26
VII	27.2 ppm	0.6	--	0.94
VIII	0	--	--	--
IX	0	--	--	--
X	47.3 ppb	0.25	0.07	0.59

TABLE 28

TABULATION OF BACTERIA SAMPLES

Sample	Sample	Location
I	D-4 oxidizer	
II	So 1	PfmA (center)
III	So 3	PfmA (8m)
IV	So 4	PfmA (8m)
V	So 5	PfmA (8m)

TABLE 29

DISTRIBUTION OF n-ALKANES IN BACTERIA SAMPLES

Sample	I	II	III	IV	V
C-12	0				
C-13					
C-14					
C-15					
C-16					
C-17					
C-18					
C-19					
C-20				0.8	
C-21				1.7	0.6
C-22				3.4	2.6
C-23		5.8		7.6	5.8
C-24		7.7	10.5	11.8	11.7
C-25		9.6	10.5	16.0	15.6
C-26		11.5	10.5	16.8	16.9
C-27		13.5	10.5	15.1	15.6
C-28		13.5	15.8	12.6	13.0
C-29		13.5	15.8	6.7	9.1
C-30		13.5	10.5	4.2	4.5
C-31		9.6	10.5	2.5	3.2
C-32		1.9	5.3	0.8	1.3
C-33					
C-34					
C-35					
C-36					
C-37					

TABLE 30

ADDITIONAL ANALYTICAL DATA FOR BACTERIA SAMPLES

Sample	Total n-Alkanes (ppm)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	0	--	--	--
II	5.2	--	--	1.08
III	3.8	--	--	0.9
IV	11.9	--	--	1.02
V	7.70	--	--	1.0

TABLE 31

TABULATION OF SHRIMP BIOASSAY SAMPLES

Sample	Source of Brine	Concentration	Hours of Exposure	Species
I	Control	--	--	white shrimp (*Penaeus setiferus*)
II	PfmB	10^{-2}	18	white shrimp (*Penaeus setiferus*)
III	PfmB	5×10^{-3}	18	white shrimp (*Penaeus setiferus*)
IV	PfmB	10^{-3}	18	white shrimp (*Penaeus setiferus*)
V	PfmB	5×10^{-3}	94	white shrimp (*Penaeus setiferus*)
VI	PfmB	10^{-3}	94	white shrimp (*Penaeus setiferus*)

TABLE 32

DISTRIBUTION OF n-ALKANES IN SHRIMP BIOASSAY SAMPLES

Sample	I	II	III	IV	V	VI
C-12						
C-13						
C-14						
C-15		2.1	11.5			
C-16		4.2	11.5			
C-17		5.3	7.8	0.8		
C-18		6.3	3.8	0.8		
C-19		4.2	3.8	0.8		
C-20		6.3		0.8		
C-21		7.4	3.8	3.2	0.8	10.0
C-22	1.5	6.3	3.8	3.2	1.6	10.0
C-23	5.1	8.4	7.8	9.7	5.6	10.0
C-24	10.3	6.3	7.8	9.7	12.0	10.0
C-25	15.4	8.4	7.8	16.1	16.8	10.0
C-26	17.4	4.2		10.5	18.4	10.0
C-27	17.4	4.2		11.3	18.8	10.0
C-28	14.4	8.4	7.8	12.9	12.8	10.0
C-29	8.2	6.3	7.8	11.3	8.0	10.0
C-30	4.1	3.2	7.8	3.2	4.0	10.0
C-31	3.1	4.2	7.8	3.2	1.6	
C-32	2.1	2.1	7.8	1.6		
C-33	1.0	1.1		0.8		
C-34		1.1				
C-35						
C-36						
C-37						

TABLE 33

ADDITIONAL ANALYTICAL DATA FOR SHRIMP BIOASSAY SAMPLES

Sample	Total n-Alkanes (ppb)	Pristane/ n-C-17	Phytane/ n-C-18	Odd/Even Preference
I	1950	--	--	1.01
II	475	1.2	0.17	1.07
III	650	1.5	--	1.36
IV	620	2.0	1.0	1.34
V	4500	--	--	1.05
VI	770	--	--	1.0

TABLE 35

DISTRIBUTION OF SULFUR IN SEDIMENT SAMPLES

Sample	Concentration of Sulfur (ppm)
LXXVII	0.87
LXXVIII	1.12
LXXIX	1.33
LXXX	0.96
LXXXI	2.49
LXXXII	3.83
LXXXIII	3.26
LXXXIV	3.25
LXXXV	11.85
LXXXVI	9.07
LXXXVII	3.47
LXXXVIII	0.3
LXXXIX	1.45
XC	3.11
XCI	3.45
XCII	3.96
XCIII	3.70
XCIV	1.92
XCV	3.05
XCVI	0.57
XCVII	4.64
XCVIII	1.08
XCIX	7.36
C	0.44
CI	4.18
CII	4.43
CIII	9.50
CIV	6.28
CV	7.33
CVI	3.0

TABLE 34

DISTRIBUTION OF SULFUR IN BRINE SAMPLES

Sample	Weight (g)	%
XXIV	0.17	0.03
XXV	0.11	0.02
XXVI	0.07	0.1
XXVII	0	0
XXVIII	0.07	0.12
XXIX	0	0
XXX	0.37	0.06
XXXI	0.36	0.05
XXXII	0.50	0.11
XXXIII	0.16	0.03
XXXIV	0.30	0.06
XXXV	0.12	0.02
XXXVI	0.25	0.04
XXXVII	0.04	0.006
XXXVIII	0.21	0.04

TABLE 36

DISTRIBUTION OF CARCINOGENS IN PLATFORM SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
XXIV	0	0
XXV	11.0	0
XXVI	1.5	133
XXVII	1.8	0
XXVIII	2.0	0
XXIX	2.5	125
XXX	1.1	167
XXXI	5.4	8.6
XXXII	1.1	58
XXXIII	1.1	0
XXXIV	0.5	46
XXXV	0	66
XXXVI	0.9	25
XXXVII	0	9
XXXVIII	1.1	11

TABLE 37

DISTRIBUTION OF CARCINOGENS IN WATER SAMPLES

Sample	Benzo[a]pyrene (ppt)	Methylnaphthalenes (ppb)
CVI	0	0
CVII	12700	0
CVIII	0	0
CIX	1.0	0
CX	0	0
CXI	0	0
CXII	0	0
CXIII	0	0
CXIV	10	0
CXV	10	0.01
CXVI	10	0.01
CXVII	2	0.01
CXVIII	0	0
CXIX	10	0
CXX	0	0
CXXI	10	0
CXXII	20	0

TABLE 38

DISTRIBUTION OF CARCINOGENS IN BARNACLE SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
XCII	4.2	0
XCIII	0	0
XCIV	3.6	0
XCV	0	0
CVIII	0	0
CIX	0	0
CXVI	20.3	0
CXVII	0	4.0
CXVIII	18.6	0
CXIX	0	1.3
CXXXII	0	4.2
CXXXIII	2.2	0

TABLE 39

DISTRIBUTION OF CARCINOGENS IN SHRIMP SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
XI	0	13.9
XII	0	14.4
XIII	0	0
XIV	0	0
XV	0	0
XVI	0	0
XVII	0	0
XVIII	0	1.3
XIX	0	0
XX	0	0
XXI	0	0
XXII	0	0
XXIII	0	0
XXIV	0	0

TABLE 40

DISTRIBUTION OF CARCINOGENS IN FISH SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
XCV	36	4.1
XCVI	6	0
XCVII	40	4.5
XCVIII	0	0
XCIX	125	0
C	15	0
CI	0	0
CII	0	0
CIII	0	0
CIV	0	0
CV	0	0.6
CVI	0	0
CVII	0	1.3
CVIII	0	0
CIX	0	3.0
CX	0	0.5
CXI	0	4.0
CXII	0	0
CXIII	0	0
CXIV	0	5.4
CXV	61	0
CXVI	0	--
CXVII	49	33.6
CXVIII	0	40.6
CXIX	93	0
CXX	7140	28.3
CXXI	0	0
CXXII	0	--
CXXIII	0	6.7
CXXIV	0	1.6
CXXV	53	0
CXXVI	0	5.2
CXXVII	895	5.6
CXXVIII	0	3.3
CXXIX	0	12.7
CXXX	0	--
CXXXI	0	0
CXXXII	0	12.8
CXXXIII	0	0
CXXXIV	0	4.0
CXXXV	0	12.7

TABLE 41

DISTRIBUTION OF CARCINOGENS IN BENTHIC SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
XVI	0	1.1
XVII	0	0
XVIII	20	0
XIX	66	0
XX	0	7.9
XXI	238	0
XXII	28	0
XXIII	0	0
XXIV	0	0
XXV	0	0
XXVI	0	13.3
XXVII	0	0
XXVIII	0	3.0
XXIX	26	0
XXX	29	0
XXXI	100	0
XXXII	59	8
XXXIII	0	1.2
XXXIV	41	9.5
XXXV	0	2.0
XXXVI	27	1.20
XXXVII	28	0
XXXVIII	8	2.67
XXXIX	0	0
XL	0	0
XLI	0	0
XLII	0	--
XLIII	0	--
XLIV	0	0
XLV	0	0
XLVI	19	0
XLVII	0	12.0
XLVIII	34	15.0

TABLE 42

DISTRIBUTION OF CARCINOGENS IN SEDIMENT SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
LXXVII	0	0.09
LXXVIII	0	0.99
LXXIX	0.38	0
LXXX	1.59	0.19
LXXXI	0.55	0
LXXXII	0.72	0.33
LXXXIII	0.44	0.14
LXXXIV	0.72	0
LXXXV	14.4	11.83
LXXXVI	35.4	0
LXXXVII	487.21	0
LXXXVIII	0.31	0.36
LXXXIX	1.09	0
XC	0.72	0.13
XCI	7.79	26.7
XCII	0.57	0
XCIII	0.27	0
XCIV	0.40	0
XCV	0.33	0
XCVI	0.47	0
XCVII	0.32	0
XCVIII	0.60	0
XCIX	0.75	0
C	0.15	0
CI	0.23	0
CII	0.23	0
CIII	0.44	0
CIV	0.33	0
CV	0.54	0.77
CVI	0.26	0

TABLE 43

DISTRIBUTION OF CARCINOGENS IN BACTERIA SAMPLES

Sample	Benzo[a]pyrene (ppt)	Methylnaphthalenes (ppb)
II	0	0
III	0	0
IV	0	0
V	0	0

TABLE 44

DISTRIBUTION OF CARCINOGENS IN SHRIMP BIOASSAY SAMPLES

Sample	Benzo[a]pyrene (ppb)	Methylnaphthalenes (ppb)
I	0	0
II	0	0
III	0	6.6
IV	0	0
V	0	33.9
VI	0	30.8

TABLE 45

DISTRIBUTION OF NUTRIENTS IN BRINE SAMPLES

Sample	Sulfate (mg/l)	Nitrate (μg/l)	Phosphate (mg/l)
XXIV	16.5	0	0
XXV	24.0	0	0
XXVI	22.5	0	0
XXVII	9.5	0	0
XXVIII	20.0	0	0
XXIX	17.0	0	0
XXX	22.0	0	0
XXXI	17.5	0	0
XXXII	24.0	0	0
XXXIII	35.0	0	0
XXXIV	44.0	200	0
XXXV	57.0	180	0
XXXVI	35.0	500	0
XXXVII	49.0	800	0
XXXVIII	36.5	500	0

TABLE 46

DISTRIBUTION OF OIL PRODUCTION CONTAMINANTS

Sample	Oil in Water (ppm)	Sulfide* (ppm)
XXIV	36	34
XXV	35	0.6
XXVI	40	<D.L.
XXVII	40	<D.L.
XXVIII	40	<D.L.
XXIX	40	<D.L.
XXX	34	<D.L.
XXXI	41	<D.L.
XXXII	37	<D.L.
XXXIII	38	<D.L.
XXXIV	38	<D.L.
XXXV	36	<D.L.
XXXVI	40	<D.L.
XXXVII	9	<D.L.
XXXVIII	10	<D.L.

* <D.L. = lower than linear range of procedure

Part B

EXECUTIVE SUMMARY

A three compartment model has been constructed, with compartments for the air/sea interface, the water column, and the sediment. The compartments are interconnected, and there is provision for external input and output for each compartment. Programs have been written in HPL for use on a Hewlett-Packard 9825A programmable calculator. Simulations have been run to effect sensitivity testing, and the use of the model to predict the effects of sediment resuspension and oil spills has been explored.

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INTRODUCTION

Prior to the commencement of the Buccaneer oilfield study, little was known concerning the environmental effects of routine operation of offshore oil and gas production facilities (Morgan *et al*., 1974; Bean *et al*., 1977; Brooks *et al*., 1977). While detailed short and long-term studies had been performed on the acute effects of accidental spills, only scattered efforts of the consequences of low-level oil discharges were available (Nelson-Smith, 1973; Farrington and Meyers, 1975; Johnston, 1976).

During the first year of the Buccaneer oilfield project we obtained a considerable amount of data pertaining to hydrocarbon levels in discharges from the production platforms and their distribution in water, sediments, molluscs, crustaceans, plankton, fish, and other biota. We have been able to supplement this collection of data during the second year of the project.

The objective of the modelling project was to evaluate these data and to use them in the construction of a model which would account for the various sources, distributions, fates, and effects of hydrocarbons in the vicinity of the oilfield. This model was to be refined as the analytical work proceeded, and was to be used to identify deficiencies in our knowledge of the hydrocarbon ecology of the Buccaneer oilfield.

METHODS AND MATERIALS

Our basic model contains three compartments:

(i) the air/sea interface,

(ii) the water column, and

(iii) the sediment.

These compartments are interconnected, and there are separate inputs and outputs for each, as shown in Figure 1.

The air/sea interface is a cylindrical portion of the water column with diameter 100 m and depth 1 m. The water column compartment has the same radius and a depth of 20 m. The sediment compartment also has a radius of 100 m but a depth of 1 cm. These dimensions reflect observations in the study area by ourselves and other contractors. The radius of 100 m was chosen for each compartment to define the immediate vicinity of a production platform. The relatively high concentrations of petroleum hydrocarbons in surficial sediments are encompassed by such a radius. The hydrocarbon pool at the air/sea interface is generally considered to be a monomolecular (or very thin) layer. Wave action, however, creates sufficient turbulence to effect some mixing in the upper water column, and we have chosen to define this compartment as having a depth of 1 m. The water depth in the vicinity of each production platform is approximately 20 m, so we have used this value for the depth of the water column compartment. It was not so easy for us to select an appropriate depth for the sediment compartment. We were aware of the hard-packed nature of the sub-surface sediment and the continual scouring of the surficial sediment. The depth chosen (1 cm) is an estimate of the thickness of the temporarily deposited material which is subject to resuspension. We measured the specific gravity of surficial sediment from below the production platforms as 2.1 and, for convenience, have employed a value of 2.0 in constructing our model.

The main input to the air/sea interface compartment is from platform discharges, principally of formation water (produced water or brine). Other platform discharges (sewage, desalination and fire-fighting overflow) will contribute to this input, as would spills or pipeline leaks. Other inputs would be from drifting surface slicks and tar balls, discharges from boats (including those of sports fishermen), and airborne hydrocarbons (originating within the oilfield or elsewhere).

Hydrocarbons from the air/sea interface can be lost from the system by evaporation, drift, or degradation. Degradation may be chemical, usually involving oxidation, or metabolic. Chemical oxidation under the influence of sunlight (perhaps catalyzed by trace metals) would lead to the formation of alcohols, aldehydes, acids, and related compounds. Metabolic degradation would also usually proceed *via* oxidative pathways and could take place in the tissues of the animal itself or could be effected by microorganisms in the digestive tract.

There are several mechanisms for transfer of hydrocarbons from the air/sea interface to the water column. These include solution and emulsification. Hydrocarbons incorporated into fecal pellets or absorbed onto other particulate matter would also enter the water column, but would continue downward to the sediment. Some hydrocarbon would also be lost from the water column by drift or degradation.

Hydrocarbons accumulating temporarily in the sediment could be degraded *in situ* or resuspended in the water column.

Our model also has provision for input of biogenic hydrocarbons to the water column and sediment compartments.

The mathematical expressions describing the fates of hydrocarbons originating in each pool are given below. Units of pool size are Kg; rates (R_1-R_3) are Kg week^{-1}; and rate constants (k_1-k_5) are week^{-1}. The initial pool sizes in the air/sea interface, water column, and sediment, are a, b, and c, respectively. The pool sizes after time t are expressed as C_y^x, where the superscript denotes the origin of the hydrocarbon and the subscript the pool refered to (A = air/sea interface, B = water column, C = sediment, D = input to air/sea interface, E = output from air/sea interface, F = output from water column, G = output from sediment, H = input to sediment, and I = input to water column).

The initial pool in the sediment will be depleted by degradation, so

$$C_C^C = ce^{-k_5 t}$$

Direct input to the sediment will also contribute to this pool, so

$$C_C^H = \frac{R_3}{K_5}\ (1 - e^{-k_5 t})$$

The initial pool in the water column will be depleted by loss from the system and to the sediment, so

$$C_B^B = be^{-(k_3+k_4)t}$$

and the contribution from this pool to the sediment will be given by

$$C_C^B = \frac{bk_4}{k_5-k_3-k_4}\,[e^{-(k_3+k_4)t} - e^{-k_5t}]$$

Direct input to the water column will also contribute to this pool, so

$$C_B^I = \frac{R_2}{k_3+k_4}\,[1 - e^{-(k_3+k_4)t}]$$

and this input will also supplement the sediment pool in the following manner

$$C_C^I = R_2k_4\ \frac{1}{k_5(k_3+k_4)} + \frac{e^{-(k_3+k_4)t}}{(k_3+k_4)(k_3+k_4-k_5)} + \frac{e^{-k_5t}}{k_5(k_5-k_3-k_4)}$$

The initial pool at the air/sea interface will be depleted, so

$$C_A^A = ae^{-(k_1+k_2)t}$$

and material initially in this pool will contribute to the pools in the water column

$$C_B^A = \frac{ak_2}{k_3+k_4-k_1-k_2}\,[e^{-(k_1+k_2)t} - e^{-(k_3+k_4)t}]$$

and the sediment

$$C_C^A = ak_2k_4\,\left[\frac{e^{-(k_1+k_2)t}}{(k_1+k_2-k_3-k_4)(k_1+k_2-k_5)} + \frac{e^{-(k_3+k_4)t}}{(k_1+k_2-k_3-k_4)(k_5-k_3-k_4)} + \frac{e^{-k_5t}}{(k_1+k_2-k_5)(k_3+k_4-k_5)}\right]$$

Finally, direct input to the air/sea interface will contribute to the pools at the air/sea interface

$$C_A^D = \frac{R_1}{k_1+k_2}\,[1 - e^{-(k_1+k_2)t}]$$

the water column

$$C_B^D = R_1 k_2 \left[\frac{1}{(k_1+k_2)(k_3+k_4)} + \frac{e^{-(k_1+k_2)t}}{(k_1+k_2)(k_1+k_2-k_3-k_4)} + \frac{e^{-(k_3+k_4)t}}{(k_3+k_4)(k_3+k_4-k_1-k_2)}\right]$$

and the sediment

$$C_C^D = R_1 k_2 k_4 \left[\frac{1}{(k_1+k_2)(k_3+k_4)k_5} + \frac{e^{-(k_1+k_2)t}}{(k_1+k_2)(k_1+k_2-k_3-k_4)(k_5-k_2-k_1)} + \frac{e^{-(k_3+k_4)t}}{(k_3+k_4)(k_1+k_2-k_3-k_4)(k_3+k_4-k_5)} + \frac{e^{-k_5 t}}{k_5(k_1+k_2-k_5)(k_5-k_3-k_4)}\right]$$

The total quantity of material in each pool is given by the expressions

$$C_A = C_A^D + C_A^A$$

$$C_B = C_B^D + C_B^A + C_B^I + C_B^B$$

$$C_C = C_C^D + C_C^A + C_C^I + C_C^B + C_C^H + C_C^C$$

Programs were written to perform these calculations on our Hewlett-Packard 9825A programmable calculator. The language used was HPL, which is very similar to BASIC. One program was used to calculate pool sizes and concentrations for output on the line printer (Figure 2), and the other for plotting concentration profiles (examples are given in the appendix). Listings of these programs are available on request.

The H.-P. 9825A has a dynamic range of 10^{99} to 10^{-99}, 0, and -10^{-99} to -10^{99}. Thus, it cannot work with numbers lower than e^{-228}. This is a slight problem in some of our calculations since, when rate constants are high, there is a limitation on the time period encompassed by a simulation. This problem can be circumvented by running serial simulations

RESULTS

We had hoped originally to make use of published data to select appropriate values for the various rate constants in our model. However, we soon found that parameters obtained from oil spill studies were inappropriate for use in a model describing the hydrocarbon ecology of the Buccaneer oilfield. Our approach in testing our model has been to select empirical values which appear to adequately account for our analytical data and to test the sensitivity of the various parameters.

After evaluating the model under equilibrium conditions, the effects of anticipated perturbations are considered.

A step-wise approach was used to derive reasonable values for the various parameters. The mean rate of discharge of oil from the platforms during the past two years has been about 10 Kg week^{-1}. In the immediate vicinity of the platforms, the mean oil concentration of oil in surface water samples has been about 50 ppb. To maintain this pool size, k_1+k_2 should be 6.0. The ratio of k_1 to k_2 and the values of k_3 to k_5 were chosen so that

(i) the oil concentration in the water column was about 0.5 ppb, and

(ii) an equilibrium concentration of 1-5 ppm of oil in the sediments was attained within a reasonable period of time.

The parameters selected (Figure 3) result in the attainment of an equilibrium concentration of about 50 ppb at the air/sea interface within one week. An appropriate equilibrium concentration was reached in the water column within two weeks. Figure 3 also shows the oil concentration in the sediment increasing rapidly, and Figure 3 indicates a concentration of 3 ppm (close to the equilibrium concentration) would be reached within 6-12 months. Of course, this would never happen in practice because the system would not remain unperturbed for such a long time period.

Figures 5 to 19 illustrate the effects of a 10-fold increase or reduction in any of the rate constants.

Variation of k_1 has a marked effect upon oil concentrations at the air/sea interface (Figure 5) and in the water column (Figure 6). An increase in the value of k_1 (which would occur if, for example, a strong current were flowing through the oilfield) would cause a large reduction in both of these pool sizes. Conversely, calm conditions during cold weather (when there is little evaporation from the air/sea interface) would result in an increase in these pool sizes. The short-term effect of a change in k_1 upon the oil concentration in the sediment is much less pronounced (Figure 7).

Since k_1 is much larger than k_2, a ten-fold change in the value of k_2 has little effect upon the value of (k_1+k_2) and, consequently, the pool size at the air/sea interface (Figure 8). There is, of course, a much more pronounced effect upon the oil concentration in the water column (Figure 9). It would be reasonable to observe a change in k_2 if, for example, there were a large increase in the zooplankton population at the air/sea interface and if these plankton were to incorporate oil into their fecal pellets. In this case, the increased pool size of the water column would not be a result of an increased concentration of dissolved oil, but of particulate material descending toward the sediment. There is only a moderate short-term increase in the sediment pool size if k_2 is increased, while a reduction of k_2 has a negligible effect upon this pool (Figure 10).

A variation in k_3 has no effect upon the pool size at the air/sea interface (Figure 11). In practice, however, variation in k_3 would usually be accompanied by similar changes in the value of k_1 (both would increase if current flow were to increase, for example). As might be expected, k_3 has a marked effect upon the pool size in the water column (Figure 12). The cumulative effect of a large increase in both k_1 and k_3 (during a storm, for example) would be particularly pronounced. Again, there is only a small short-term change in the pool size in the sediment if k_3 is varied (Figure 13).

Variation of k_4 has no effect upon the pool size at the air/sea interface (Figure 14). The effects of a change in k_4 upon the pool sizes in the water column (Figure 15) and sediment (Figure 16) are the reverse of those resulting from a change in k_3 and are of a similar magnitude.

A change in k_5 affects only the pool size in the sediment (Figures 17-19). A decrease in k_5 has little effect, whereas an increase leads to a much more notable effect. The main influence upon k_5 would be the activity of oil-degrading bacteria, and it can be seen (Figure 19) that a 10-fold increase in this activity has an effect which would be both rapid and pronounced.

An increase or decrease in the discharge rate from the production platforms would result in a corresponding change in the pool sizes of each compartment. A ten-fold change in R_1 would lead to a new equilibrium value at the air/sea interface within one week (Figure 20) and in the water column within one month (Figure 21). The sediment pool size responds to a change in R_1 much more slowly (Figure 22).

We have almost no data concerning the notes of production of biogenic hydrocarbons, and the simulations illustrated in Figures 23 and 24 cannot be considered very reliable. An input of 1 Kg week^{-1} of biogenic hydrocarbons to the water column would increase this pool size four-fold within a month (Figure 23) and would result in a slight short-term increase in the sediment pool size (Figure 24). A similar rate of production of biogenic hydrocarbons in the sediment would have a much more pronounced effect on this pool (Figure 24). Such changes would be expected if an increased rate of sulfur discharge from the production platforms were to result in an increased population of hydrocarbon-synthesizing, sulfur-utilizing bacteria.

We have also used our model to investigate the possible effects of sediment resuspension, which is now known to play a major role in the distribution of oilfield pollutants in our study area.

If sediment containing our equilibrium concentration of 3.86 ppm of oil is suspended into the water column, the oil concentration in the latter would initially be almost 4 ppb. This would return to 0.5 ppb within a month (Figure 25). Within the same time period, about half of the oil would be redeposited in the sediment (Figure 26) After resuspension of the sediment, it would be unreasonable to expect deposition to be initiated instantly, so we have considered the possible effect of a time delay between resuspension and deposition. Figure 27 illustrates the difference between water column concentrations with ($k_4 = 0.4$) and without ($k_4 = 0$) deposition for a one week period. There is surprisingly little difference between these curves, and there is only a slight reduction in the eventual sediment pool size (Figure 28). In practice, conditions (such as turbulent current flow) which would be compatible with such a delay in deposition would probably involve an increase in k_3, so the resulting sediment pool size would be further reduced.

Finally, we have been tempted to make some predictions concerning the effects of an event which has recently happened in the Buccaneer oilfield and others which might occur before our study is complete.

Until November, 1977 brine was being discharged from both production platforms, but it is now discharged only from Platform B. If our values for k_1 to k_5 are reasonable, depuration of the sediments below Platform A should proceed as illustrated in Figure 29. No sediment samples have been collected since brine discharge ceased, and the next sampling is scheduled for August, 1978. We would expect these sediments to contain about 500 ppb of oil. Weathering during the ensuing period would deplete samples of the lighter alkanes, so it may be difficult to distinguish the heavier petroleum alkanes from biogenic alkanes.

We would also like to speculate upon the consequences of a small oil spill of a similar magnitude (1 bbl) to those which have previously been reported in the Buccaneer oilfield. The initial concentration at the air/sea interface (assuming, as always, complete homogeneity) would be about 5 ppm. This would decrease to the equilibrium value within one week (Figure 30). There would be a transient increase in the water column concentration (reaching 6 ppb within three days), but this would decrease to normal within one month (Figure 31). The sediment concentration would rise only by about 50% (reaching a maximum within one month) and would return to its former value within one year (Figure 32). Actually, the sediment concentration would never exceed its normal range. The environment surrounding the Buccaneer oilfield would appear, therefore, to be capable of tolerating a small spill.

The effects of a larger spill are more difficult to predict. The simulations shown in Figures 33-37 employ our standard parameters, and illustrate the possible consequences of a 1,000 bbl spill. The initial oil concentration at the air/sea interface is 0.5%, but would return to normal within one week (Figure 33). As in the case of the smaller spill, a concentration maximum would be reached in the water column within three days, but it would have a magnitude of almost 6 ppm (Figure 34) and would require ten weeks to return to normal (Figure 35). The effect upon the sediment would be much more pronounced and long-lasting (Figure 36). A maximum concentration of more than 0.25% would be reached in about four weeks, and a concentration in excess of 500 ppm would remain after 37 weeks. A spill of this magnitude would be expected to have a significant effect upon the environment.

DISCUSSION

In this section, an attempt is made to assess the relative sensitivity of the parameters used in our model.

The only rate constants which affect the air/sea interface pool are k_1 and k_2. In fact, it is the sum of these values which controls the size of this pool. We have found that, to obtain a sufficiently low concentration of oil in the water column, k_1 should be much larger than k_2. Thus, a 10-fold change in the value of k_2 has little effect upon the air/sea interface pool. Variation in k_1 has a marked effect, as might be expected.

The pool size in the water column is greatly influenced by changes in all of the rate constants except k_5. It is difficult for us to assess the significance of these variations since we have analytical data for only one water sample from the water column. The total alkane concentration of this sample (II, collected adjacent to Platform A on June 5, 1976) was 3.4 ppb, but the concentration of C_{13} to C_{20} petroleum alkanes was only 0.51 ppb. All of the other water samples have been collected from near the surface or bottom.

The concentration of oil in the sediments is moderately increased if k_1 is decreased or k_2 increased. k_3 and k_4 have little influence upon this pool. A reduction in the magnitude of k_5 has only a small effect but, if it is increased, the sediment pool is depleted markedly.

The rates of input of petroleum and biogenic hydrocarbons to the system have a pronounced long-term effect upon each of the three pools but, in some cases, it may take many weeks for these pool sizes to reach new equilibrium values.

Time was also an important factor in deriving the "standard" rate constants which we have employed. In one of our initial simulations an equilibrium value of 5 ppm was obtained for the sediment, but it required 60,000 years to achieve this concentration. Our "standard" values allow for relatively rapid response by each pool to external influences.

The rate constants also provide an indication of the fraction of the discharged oil which enters each pool. All of the oil initially enters the air/sea interface, but $5.8/(5.8 + 0.2) = 97\%$ is lost from the system (by evaporation and degradation) and 3.3% enters the water column. Of this amount, $0.7/(0.7 + 0.4) = 64\%$ is lost by drift and 36% (or 1.2% of the original amount of discharged oil) reaches the sediment.

CONCLUSIONS

Data generated by our model are consistent with out analytical data. The major conclusions which we can draw from this work are:

(i) oil concentrations at the air/sea interface and in the water column are greatly influenced by current flow and, perhaps, meteorological conditions which would affect evaporation from the surface.

(ii) the relatively high concentrations of oil found in the sediments can be accounted for only if there is active transport of oil from the air/sea interface. It is inconceivable that solution at the surface and diffusion through the water column would be efficient enough for as much as 1.2% of the discharged oil to reach the sediment, particularly if any current were flowing through the oilfield. Possible modes of transport would include incorporation into fecal pellets (of zooplankton, barnacles, or other animals) or adsorption onto sulfur or other particulates.

(iii) a substantial fraction of suspended particulate matter can be redeposited in the sediment if the current flow is not excessive.

(iv) the environment surrounding the Buccaneer oilfield can probably tolerate a small oil spill, but long-lasting effects would result from a large spill.

We have encountered several difficulties in this work, mostly related to an inadequacy of data. The most serious deficiencies are:

(i) a lack of information concerning the rates of production of biogenic hydrocarbons.

(ii) a paucity of data concerning hydrocarbon concentration profiles throughout the water column.

(iii) an absence of experimental data concerning rates of interchange of hydrocarbons between compartments of the model.

Finally, we should acknowledge the fact that this model provides a vast oversimplification of conditions in the oilfield. We are of the opinion, however, that there are insufficient experimental data available to support the use of a more sophisticated model.

BIBLIOGRAPHY

Bean, R. M., J. W. Blaylock, E. A. Sutton, R. E. Wildung, and F. M. Davidson (1977), "Characterization of Sediments in the Vicinity of Offshore Petroleum Production," in T. F. Yen (ed.), "Chemistry of Marine Sediments," Ann Arbor Science Publishers, Ann Arbor, pp. 39-53.

Brooks, J. M., B. B. Bernard, and W. M. Sackett (1977), "Input of Low-Molecular-Weight Hydrocarbons from Petroleum Operations into the Gulf of Mexico," in D. A. Wolfe (Ed.), "Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms," Pergamon Press, New York, pp. 373-384.

Farrington, J. W., and P. A. Meyer (1975), "Hydrocarbons in the Marine Environment," in G. Eglinton (Senior Reporter), "Specialist Periodical Report: Environmental Chemistry," The Chemical Society, London, Vol. 1, pp. 109-136.

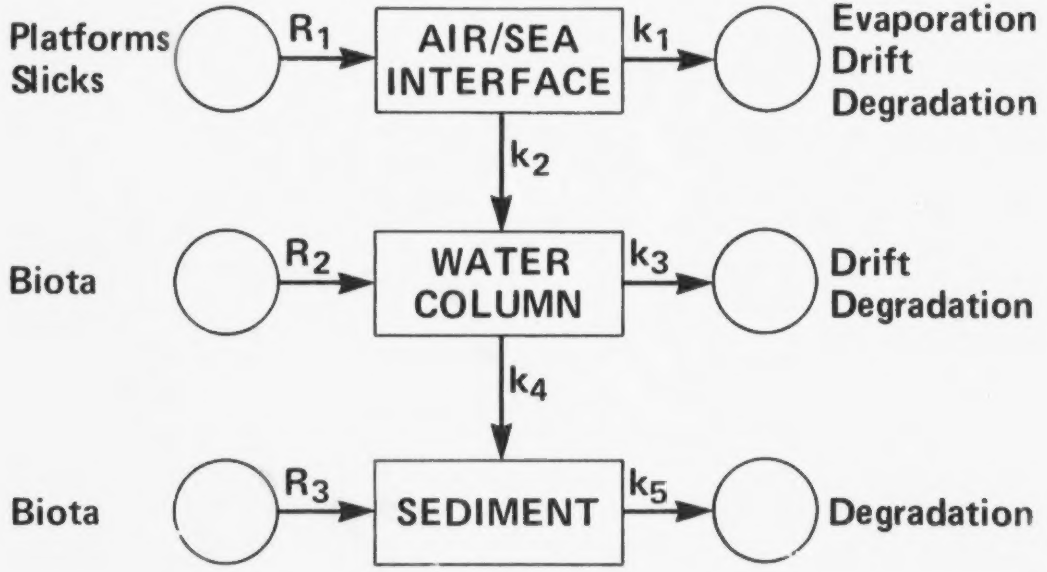
Johnston, R. (Ed.) (1976), "Marine Pollution," Academic Press, London.

Morgan, J. P., R. J. Menzies, S. Z. El-Sayed, and C. H. Oppenheimer (1974), "The Offshore Ecology Investigation: Final Project Planning Council Consensus Report," Gulf Universities Research Consortium, Galveston.

Nelson-Smith, A. (1973), "Oil Pollution and Marine Ecology," Plenum Press, New York.

APPENDIX

HYDROCARBON ECOLOGY MODEL


Platforms
Slicks
R1
AIR/SEA INTERFACE
k1
Evaporation
Drift
Degradation
k2
Biota
R2
WATER COLUMN
k3
Drift
Degradation
k4
Biota
R3
SEDIMENT
k5
Degradation

```
                    UNIVERSITY OF HOUSTON
                DEPT. OF BIOPHYSICAL SCIENCES
                  HYDROCARBON ECOLOGY MODEL


TIME INTERVAL:  37.00 weeks


RATE:                    (kg/wk)

 R(1)                    10.00
 R(2)                     0.00
 R(3)                     0.00


CONC.:                 initial                        final
                   (ppb)           (kg)         (ppb)          (kg)

 A/SI              0.00           0.000         53.05          1.667
 W/C               0.00           0.000          0.48          0.303
 SED.              0.00           0.000       3217.40          2.022


RATE CONST.:             (1/wk)

 K(1)                    5.8000
 K(2)                    0.2000
 K(3)                    0.7000
 K(4)                    0.4000
 K(5)                    0.0500



SIMULATION NUMBER    1
```

COMPUTER PROGRAM PLOT ROUTINE

```
: dim R[3],K[5],A[301],B[301],C[301],T[301],A,B,C,T
: "TAB-PLOT":ldf 4,R[*],K[*],A[*],B[*],C[*],T[*],A,B,C,T
: 1→X
: dsp "TIME INTERVAL",T;ent "",T
: dsp "INITAL [A/SI]=",A,"ppb";ent "",A;πA/100→A[1]
: dsp "INITIAL [W/C]=",B,"ppb";ent "",B;20πB/100→B[1]
: dsp "INITIAL [SED.]=",C,"ppb";ent "",C;πC/5000→C[1]
  dsp "RATE 1=",R[1],"kg/wk";ent "",R[1]
  dsp "RATE 2=",R[2],"kg/wk";ent "",R[2]
  dsp "RATE 3=",R[3],"kg/wk";ent "",R[3]
: dsp "K[1]=",K[1],"1/wk";ent "",K[1]
: dsp "K[2]=",K[2],"1/wk";ent "",K[2]
: dsp "K[3]=",K[3],"1/wk";ent "",K[3]
: dsp "K[4]=",K[4],"1/wk";ent "",K[4]
: dsp "K[5]=",K[5],"1/wk";ent "",K[5]
: "PLT":
: "A/SI":ent "PLOT [A/SI]?  0=no  1=yes",Z;1→J
: if 0=Z;gsb "W/C"
: gsb "PLT 2"
19: "W/C":ent "PLOT [W/C]?  0=no  1=yes",Z;2→J
20: if 0=Z;gsb "SED"
21: gsb "PLT 2"
22: "SED":ent "PLOT [SED.]?  0=no  1=yes",Z;3→J
23: if 0=Z;gto 93
24: gsb "PLT 2"
25: "PLT 2":dsp "PLOTTER READY?";stp
26: ent "PLOT AXIS?  0=no  1=yes",P;pen;if P=0;gsb "PLT 3"
27: ent "MAXIMUM TIME (wks)?",T
28: ent "MARK AT ?",M,"LABEL AT ?",L
  : ent "MAXIMUM CONC.? (ppb)",D
  : ent "MARK AT ?",N,"LABEL AT ?",Q
  : scl -4M,T+M,-3N,D+N
  : axe 0,0,M,N;fxd 0
  : csiz 1,1.2,8.5/11,0;0→G
  : Q+G→G;plt 0,G,1;cplt -5+(G<1000)+(G<100)+(G<10),-.3
  : if G>D;jmp 2
  : lbl G;jmp -2
  : csiz 1,1.2,8.5/11,0;0→G
  : L+G→G;plt G,0,1
  : cplt -1.3-(G>=100)-(G>=10),-1.3
  : if G>T;jmp 2
  : lbl G;jmp -3
  : csiz 1.5,1.7,8.5/11,0;plt T/2,0;cplt -6,-2.3;lbl "TIME (wks)"
  : csiz 1.5,1.7,8.5/11,90;plt 0,D/2;cplt -5.5,6-(G<1000)-(G<100)-(G<10
  : lbl "CONC. (ppb)";fxd 2
  : csiz
  : "PLT 3":if J>1;gsb "
47: (R[1]/(K[1]+K[2]))(                                    A[2]
```

COMPUTER PROGRAM PLOT ROUTINE (Continued)

```
                     )T[X])→A[3]

                     ;X+1→X
51: if X>301;jmp 2
52: T[X-1]+T/300→T[X];gsb "PLT 3"
53: 1→X;gsb "W/C"
54: "B's":if J>2;gsb "C's"
55: 1/(K[1]+K[2])(K[3]+K[4])→B[2]
56: B[2]+exp(-(K[1]+K[2])T[X])/-(K[1]+K[2])(-K[1]-K[2]+K[3]+K[4])→B[2]
57: B[2]+exp(-(K[3]+K[4])T[X])/-(K[3]+K[4])(K[1]+K[2]-K[3]-K[4])→B[2]
58: R[1]K[2]B[2]→B[2]
59: exp(-(K[1]+K[2])T[X])-exp(-(K[3]+K[4])T[X])→B[3]
60: (A[1]K[2]/(K[3]+K[4]-K[1]-K[2]))B[3]→B[3]
61: (R[2]/(K[3]+K[4]))(1-exp(-(K[3]+K[4])T[X]))→B[4]
62: B[1]exp(-(K[3]+K[4])T[X])→B[5]
63: B[2]+B[3]+B[4]+B[5]→B[6]
64: plt T[X],B[6]*100/20π;X+1→X
65: if X>301;jmp 2
66: T[X-1]+T/300→T[X];gsb "B's"
67: 1→X;gsb "SED"
68: "C's":if J>3;gto 1
69: 1/(K[1]+K[2])(K[3]+K[4])K[5]→C[2]
70: exp(-(K[1]+K[2])T[X])→F
71: F/-(K[2]+K[1])(K[4]+K[3]-K[2]-K[1])(K[5]-K[2]-K[1])→F
72: C[2]+F→C[2]
73: exp(-(K[4]+K[3])T[X])→F
74: F/-(K[4]+K[3])(K[1]+K[2]-K[3]-K[4])(K[5]-K[3]-K[4])→F
75: C[2]+F→C[2]
76: exp(-K[5]T[X])/-K[5](K[1]+K[2]-K[5])(K[3]+K[4]-K[5])→F
77: R[1]K[2]K[4](C[2]+F)→C[2]
78: exp(-(K[1]+K[2])T[X])/(K[3]+K[4]-K[1]-K[2])(K[5]-K[1]-K[2])→C[3]
79: C[3]+exp(-(K[3]+K[4])T[X])/(K[1]+K[2]-K[3]-K[4])(K[5]-K[3]-K[4])→C[3]
80: C[3]+exp(-K[5]T[X])/(K[1]+K[2]-K[5])(K[3]+K[4]-K[5])→C[3]
81: A[1]K[2]K[4]C[3]→C[3]
82: 1/(K[3]+K[4])K[5]→C[4]
83: C[4]+exp(-(K[3]+K[4])T[X])/(-K[3]-K[4])(-K[3]-K[4]+K[5])→C[4]
84: C[4]+exp(-K[5]T[X])/-K[5](K[3]+K[4]-K[5])→C[4]
85: R[2]K[4]C[4]→C[4]
86: (B[1]K[4]/(K[5]-K[3]-K[4]))(exp(-(K[3]+K[4])T[X])-exp(-K[5]T[X]))→C[5]
87: (R[3]/K[5])(1-exp(-K[5]T[X]))→C[6]
88: C[1]exp(-K[5]T[X])→C[7]
89: C[2]+C[3]+C[4]+C[5]+C[6]+C[7]→C[8]
90: plt T[X],C[8]*5000/π;X+1→X
91: if X>301;jmp 2
92: T[X-1]+T/300→T[X];gsb "C's"
93: rcf 4,R[*],K[*],A[*],B[*],C[*],T[*],A,B,C,T
94: 1→X;gsb "TAB-PLOT"
*16230
```

COMPUTER PROGRAM TABULATE ROUTINE

```
0: dim R[3],K[5],A[4],B[6],C[8],A,B,C,T,J
1: ldf 1,R[*],K[*],A[*],B[*],C[*],A,B,C,T,J
2: dsp "SIMULATION NUMBER?",J;ent "",J
3: dsp "TIME INTERVAL?",T;ent "",T
4: dsp "INITIAL [A/SI]=",A,"ppb";ent "",A;π*A/100→A[1]
5: dsp "INITIAL [W//C]=",B,"ppb";ent "",B;π*B*20/100→B[1]
6: dsp "INITIAL [SED.]=",C,"ppb";ent "",C;π*C/5000→C[1]
7: dsp "RATE 1=",R[1],"kg/wk";ent "",R[1]
8: dsp "RATE 2=",R[2],"kg/wk";ent "",R[2]
9: dsp "RATE 3=",R[3],"kg/wk";ent "",R[3]
10: dsp "K(1)=",K[1],"1/wk";ent "",K[1]
11: dsp "K(2)=",K[2],"1/wk";ent "",K[2]
12: dsp "K(3)=",K[3],"1/wk";ent "",K[3]
13: dsp "K(4)=",K[4],"1/wk";ent "",K[4]
14: dsp "K(5)=",K[5],"1/wk";ent "",K[5]
15: dsp "CALCULATING   PLEASE WAIT"
16: "CALC":
17: (R[1]/(K[1]+K[2]))(1-exp(-(K[1]+K[2])T))→A[2]
18: A[1]exp(-(K[1]+K[2])T)→A[3]
19: A[2]+A[3]→A[4]
20: 1/(K[1]+K[2])(K[3]+K[4])→B[2]
21: B[2]+exp(-(K[1]+K[2])T)/-(K[1]+K[2])(-K[1]-K[2]+K[3]+K[4])→B[2]
22: B[2]+exp(-(K[3]+K[4])T)/-(K[3]+K[4])(K[1]+K[2]-K[3]-K[4])→B[2]
23: R[1]K[2]B[2]→B[2]
24: exp(-(K[1]+K[2])T)-exp(-(K[3]+K[4])T)→B[3]
25: (A[1]K[2]/(K[3]+K[4]-K[1]-K[2]))B[3]→B[3]
26: (R[2]/(K[3]+K[4]))(1-exp(-(K[3]+K[4])T))→B[4]
27: B[1]exp(-(K[3]+K[4])T)→B[5]
28: 1/(K[1]+K[2])(K[3]+K[4])K[5]→C[2]
29: exp(-(K[1]+K[2])T)→F
30: F/-(K[2]+K[1])(K[4]+K[3]-K[2]-K[1])(K[5]-K[2]-K[1])→F
31: C[2]+F→C[2]
32: exp(-(K[4]+K[3])T)→F
33: F/-(K[4]+K[3])(K[1]+K[2]-K[3]-K[4])(K[5]-K[3]-K[4])→F
34: C[2]+F→C[2]
35: exp(-K[5]T)/-K[5](K[1]+K[2]-K[5])(K[3]+K[4]-K[5])→F
36: R[1]K[2]K[4](C[2]+F)→C[2]
37: exp(-(K[1]+K[2])T)/(K[3]+K[4]-K[1]-K[2])(K[5]-K[1]-K[2])→C[3]
38: C[3]+exp(-(K[3]+K[4])T)/(K[1]+K[2]-K[3]-K[4])(K[5]-K[3]-K[4])→C[3]
39: C[3]+exp(-K[5]T)/(K[1]+K[2]-K[5])(K[3]+K[4]-K[5])→C[3]
40: A[1]K[2]K[4]C[3]→C[3]
41: 1/(K[3]+K[4])K[5]→C[4]
42: C[4]+exp(-(K[3]+K[4])T)/(-K[3]-K[4])(-K[3]-K[4]+K[5])→C[4]
43: C[4]+exp(-K[5]T)/-K[5](K[3]+K[4]-K[5])→C[4]
44: R[2]K[4]C[4]→C[4]
45: (B[1]K[4]/(K[5]-K[3]-K[4]))(exp(-(K[3]+K[4])T)-exp(-K[5]T))→C[5]
[illegible] exp(-K[5]T))→C[6]
[illegible] [7]
```

COMPUTER PROGRAM TABULATE ROUTINE (Continued)

```
                [4]+B[5]→B[6]
                [4]+C[5]+C[6]+C[7]→C[8]
50: dsp  TABULATING"
51: "TAB":
52: fmt 1,3/,29x,"UNIVERSITY OF HOUSTON";wrt 6.1
53: fmt 2,1/,25x,"DEPT. OF BIOPHYSICAL SCIENCES";wrt 6.2
54: fmt 3,1/,27x,"HYDROCARBON ECOLOGY MODEL",3/;wrt 6.3
55: fmt 4,10x,"TIME INTERVAL: ",f6.2,1x,"weeks",3/;wrt 6.4,T
56: fmt 5,10x,"RATE:",20x,"(kg/wk)",2/;wrt 6.5
57: fmt 11x,"R(1)",18x,f7.2,1/;wrt 6,R[1]
58: fmt 11x,"R(2)",18x,f7.2,1/;wrt 6,R[2]
59: fmt 11x,"R(3)",18x,f7.2,3/;wrt 6,R[3]
60: fmt 10x,"CONC.:",18x,"initial",18x,"final";wrt 6
61: fmt 29x,"(ppb)",8x,"(kg)",7x,"(ppb)",7x,"(kg)",2/;wrt 6
62: fmt 11x,"A/SI",07x,f12.2,2x,f11.3,4x,f7.2,5x,f7.3,1/
63: wrt 6,A,A[1],A[4]*100/π,A[4]
64: fmt 11x,"W/C ",12x,f7.2,6x,f7.3,4x,f7.2,5x,f7.3,1/
65: wrt 6,B,B[1],B[6]*100/20π,B[6]
66: fmt 11x,"SED.",11x,f8.2,6x,f7.3,1x,f10.2,2x,f10.3,3/
67: wrt 6,C,C[1],C[8]*5000/π,C[8]
68: fmt 10x,"RATE CONST.:",13x,"(1/wk)",2/;wrt 6
69: 1→V
70: fmt 11x,"K(",f1.0,")",18x,f8.4,1/;wrt 6,V,K[V]
71: 1+V→V;if V<=5;jmp -1
72: fmt 5/,10x,"SIMULATION NUMBER ",f3.0,6/;wrt 6,J
73: fmt 8x,"------------------------------------------------------------------",1/
74: wrt 6
75: rcf 1,R[*],K[*],A[*],B[*],C[*],A,B,C,T,J
76: gto 1
```

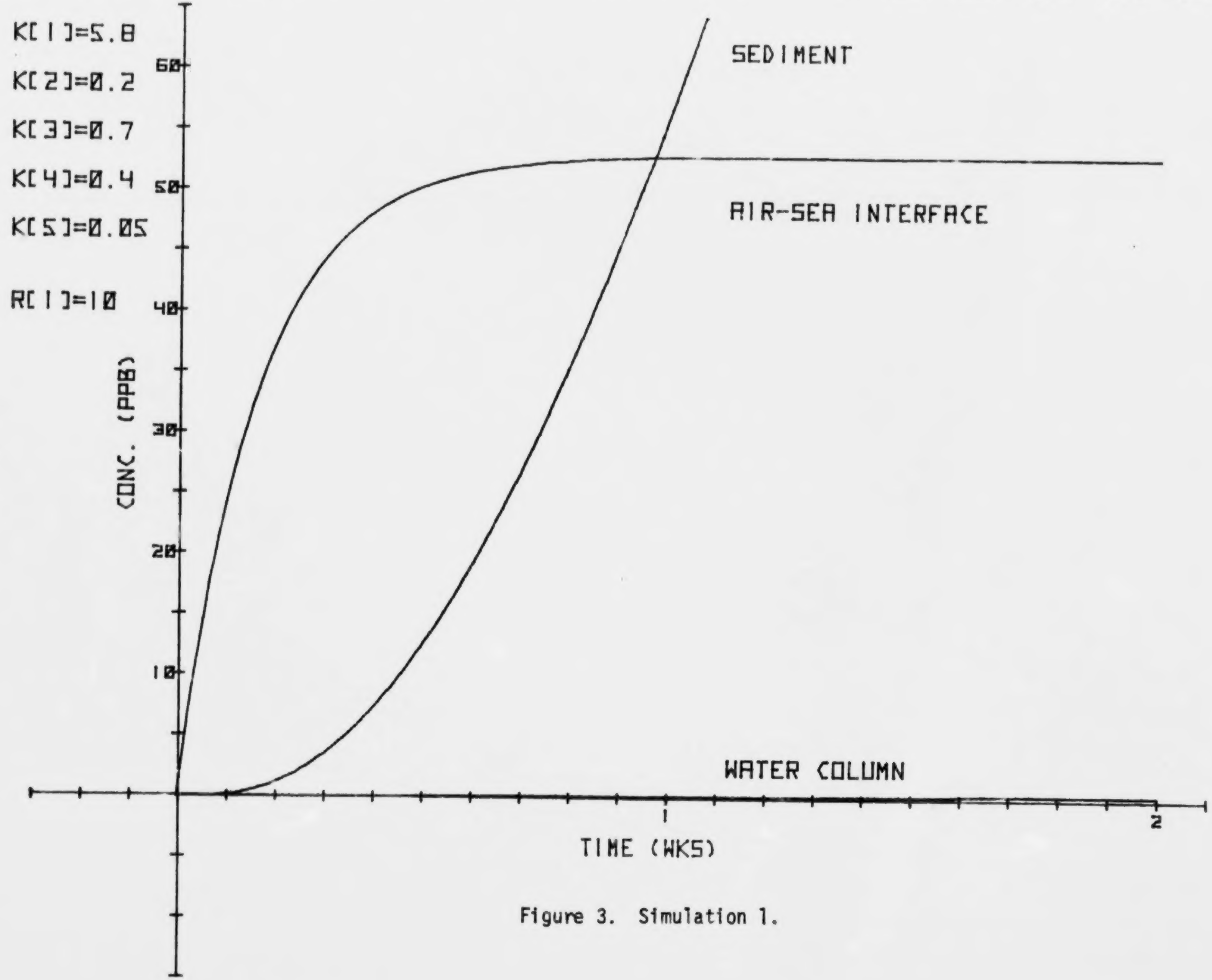


Figure 3. Simulation 1.

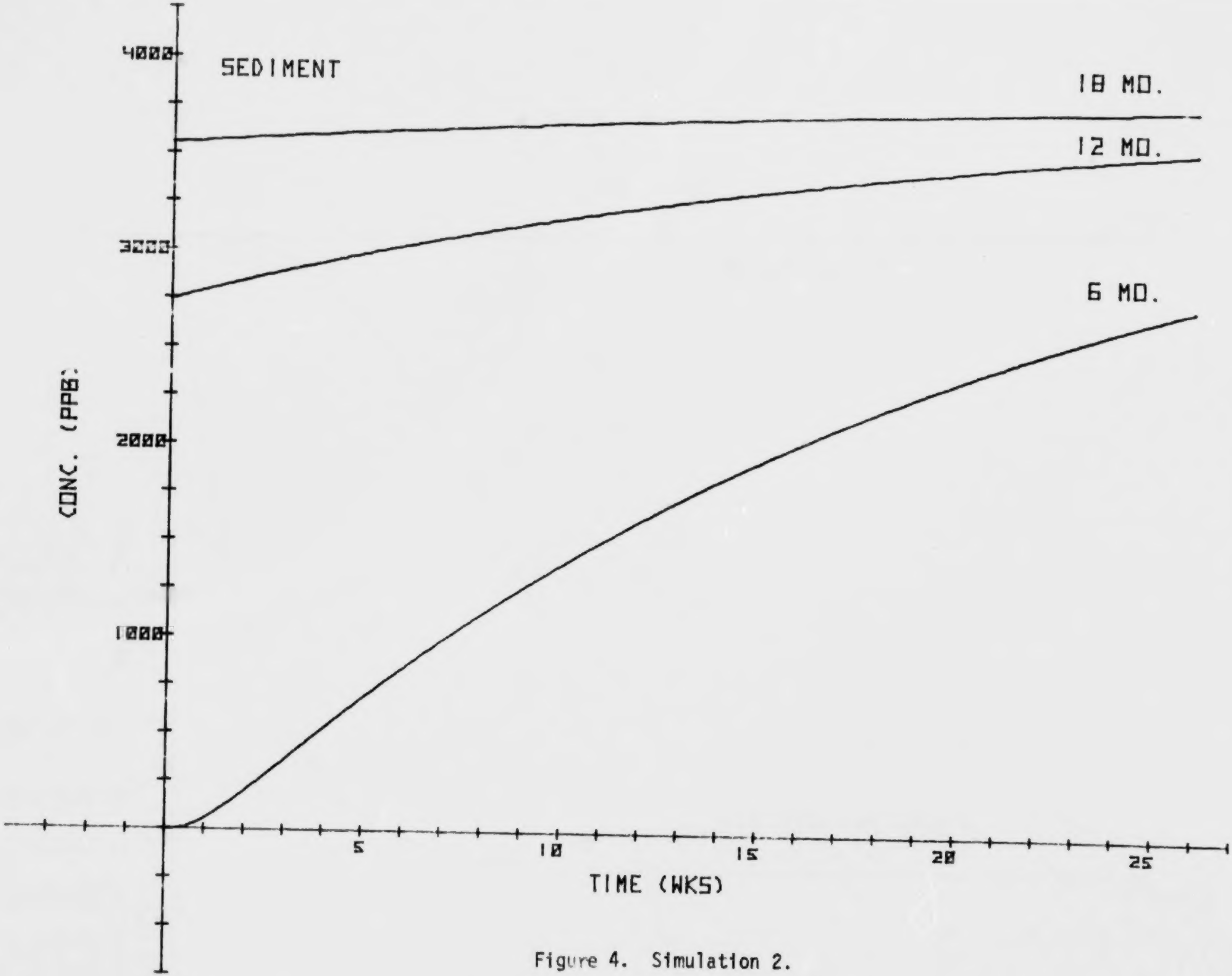
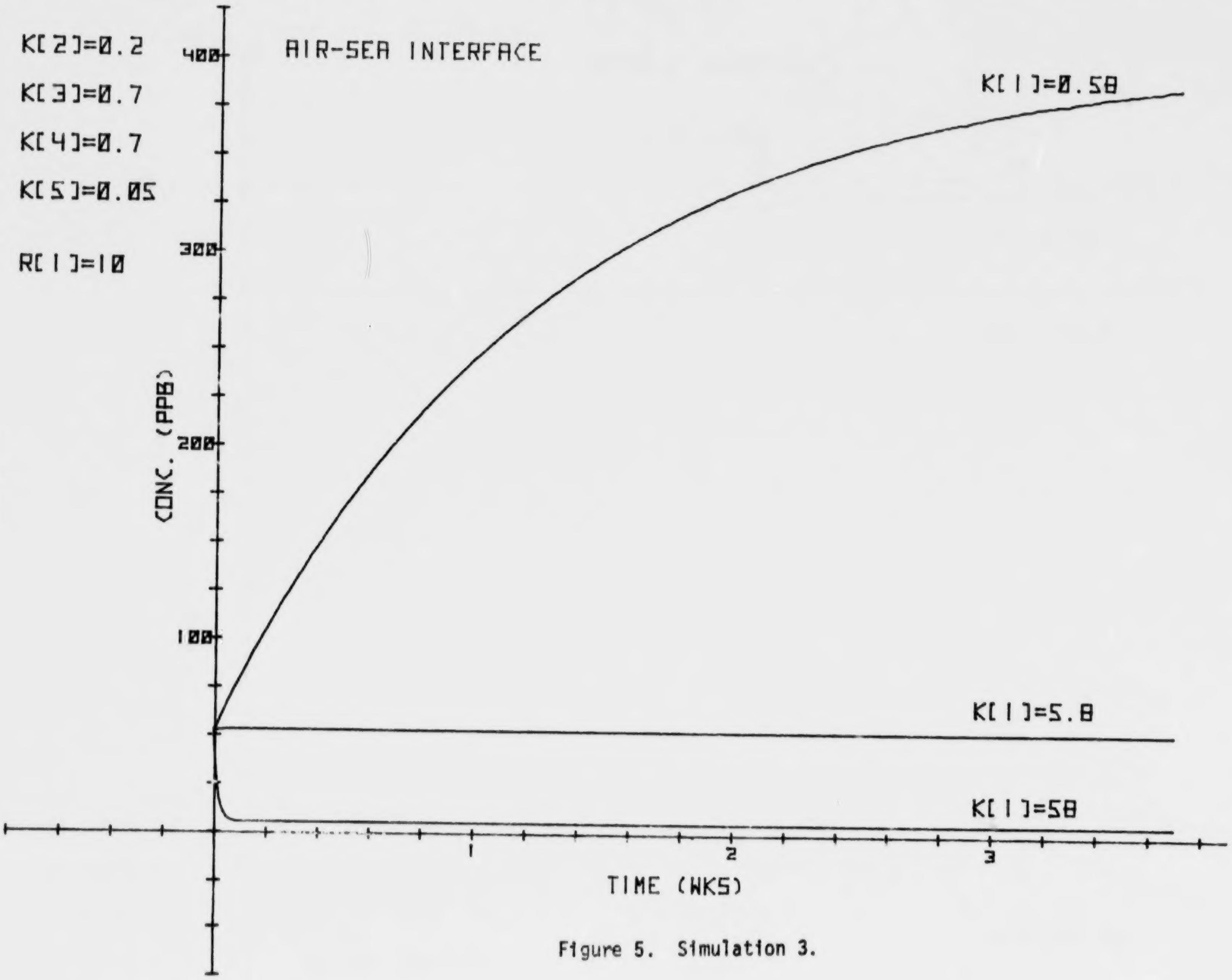


Figure 4. Simulation 2.



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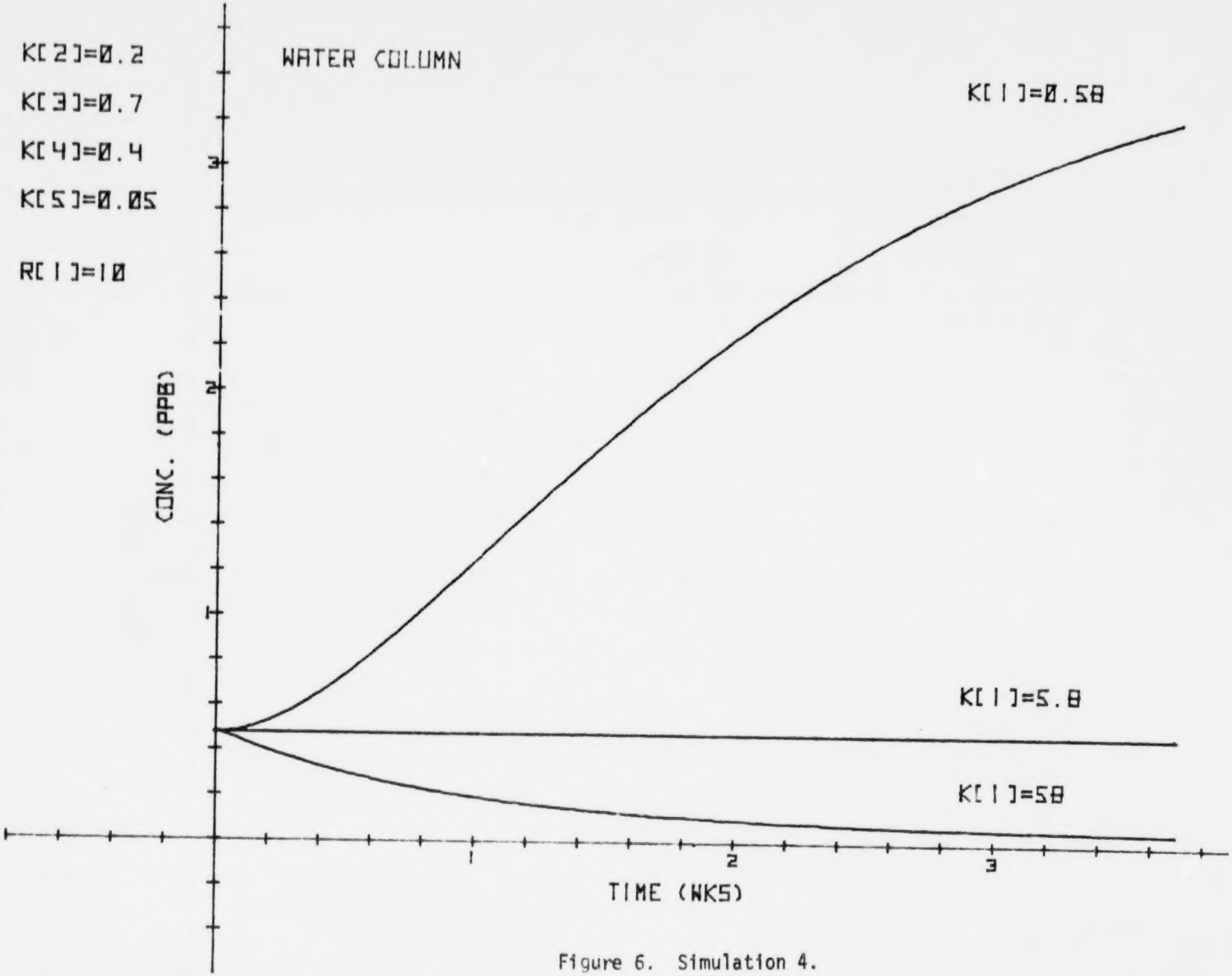

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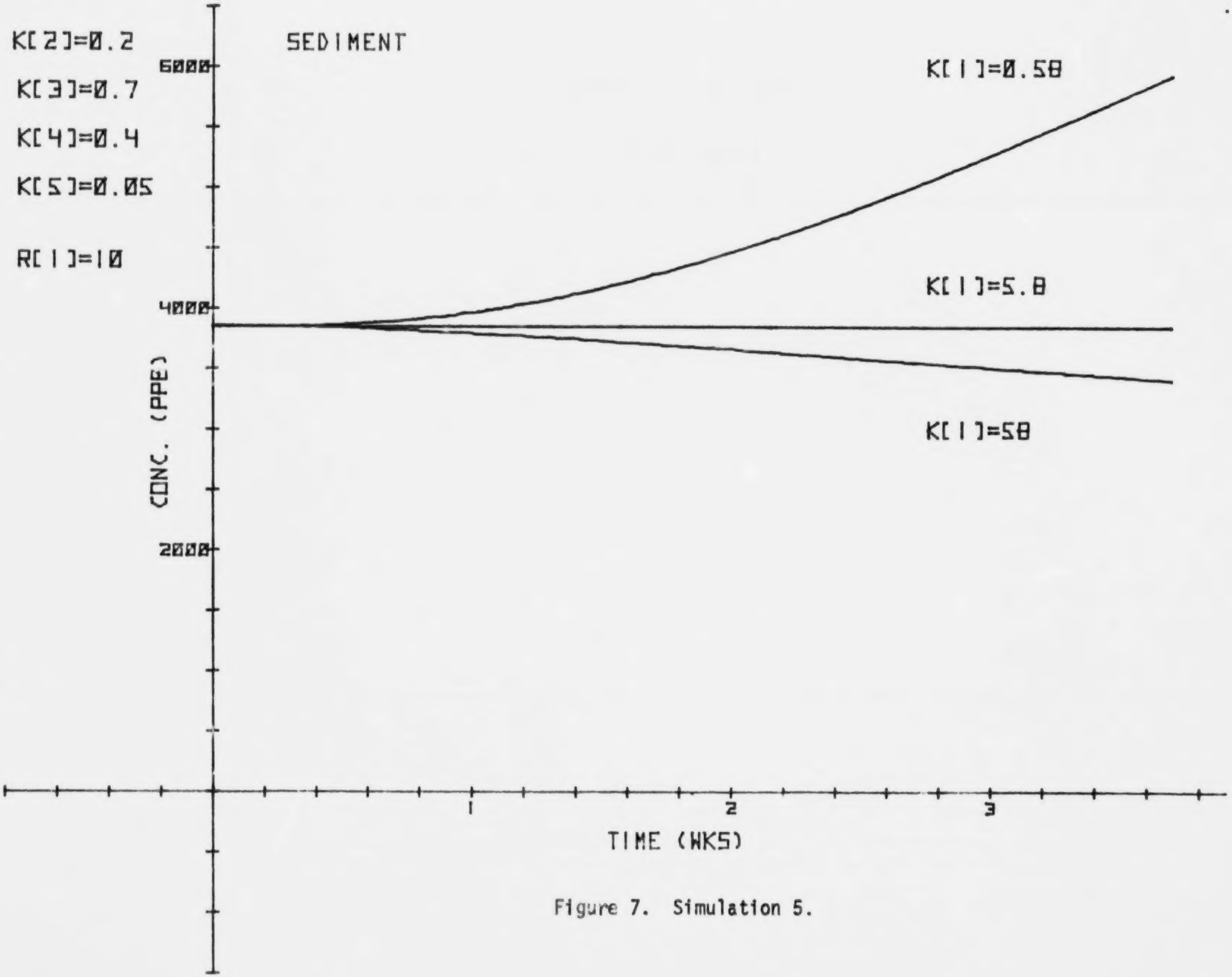

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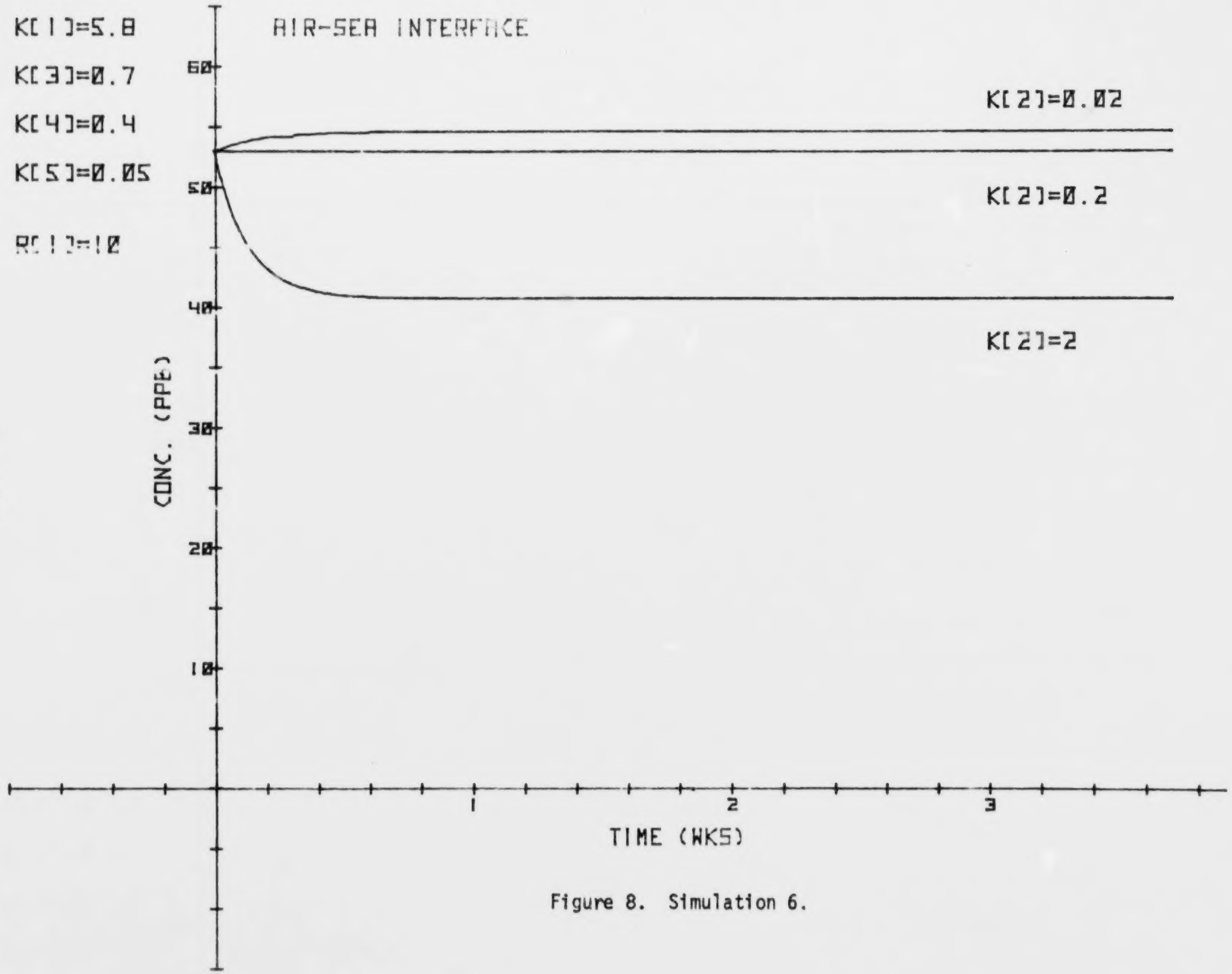

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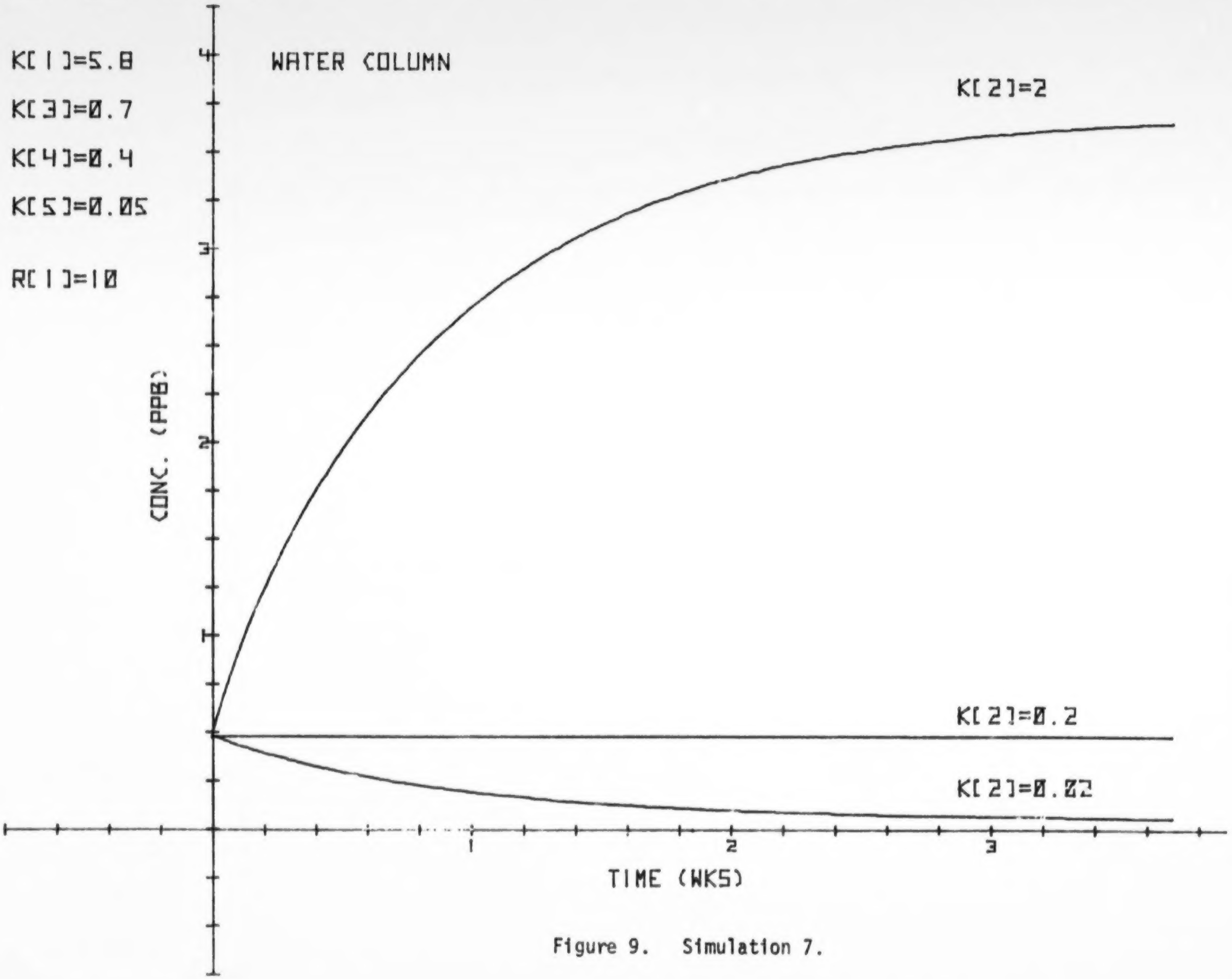

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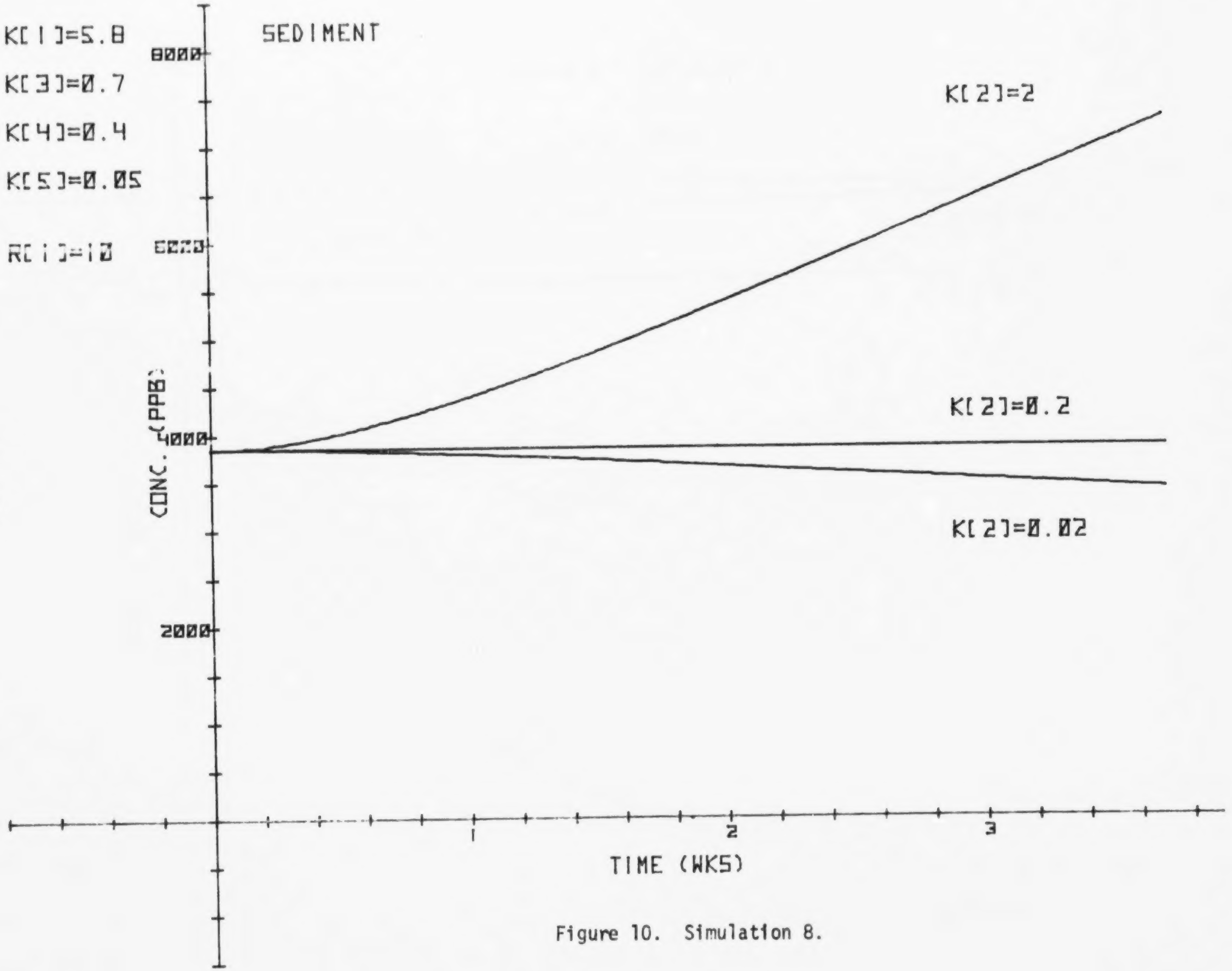


Figure 10. Simulation 8.

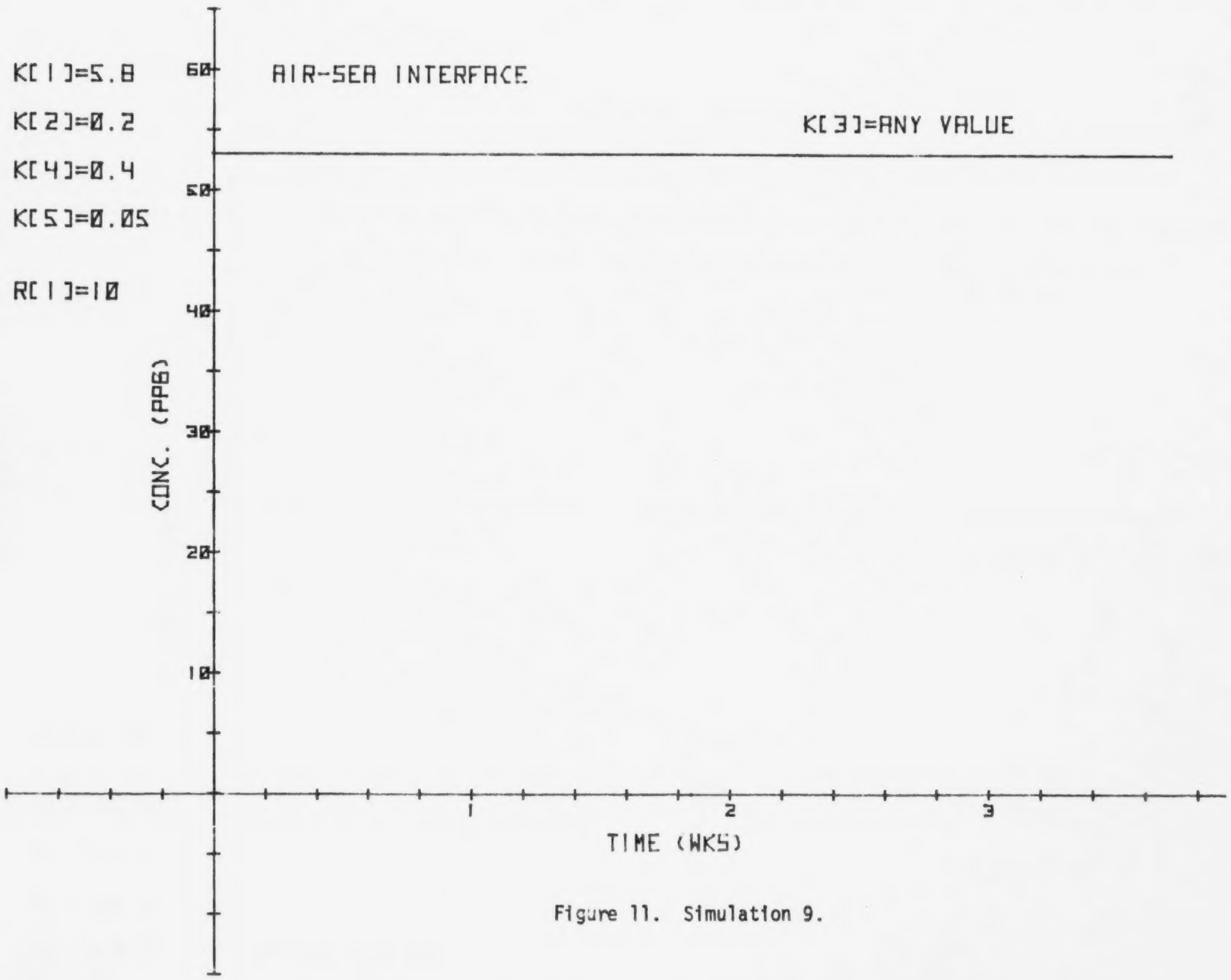


Figure 11. Simulation 9.

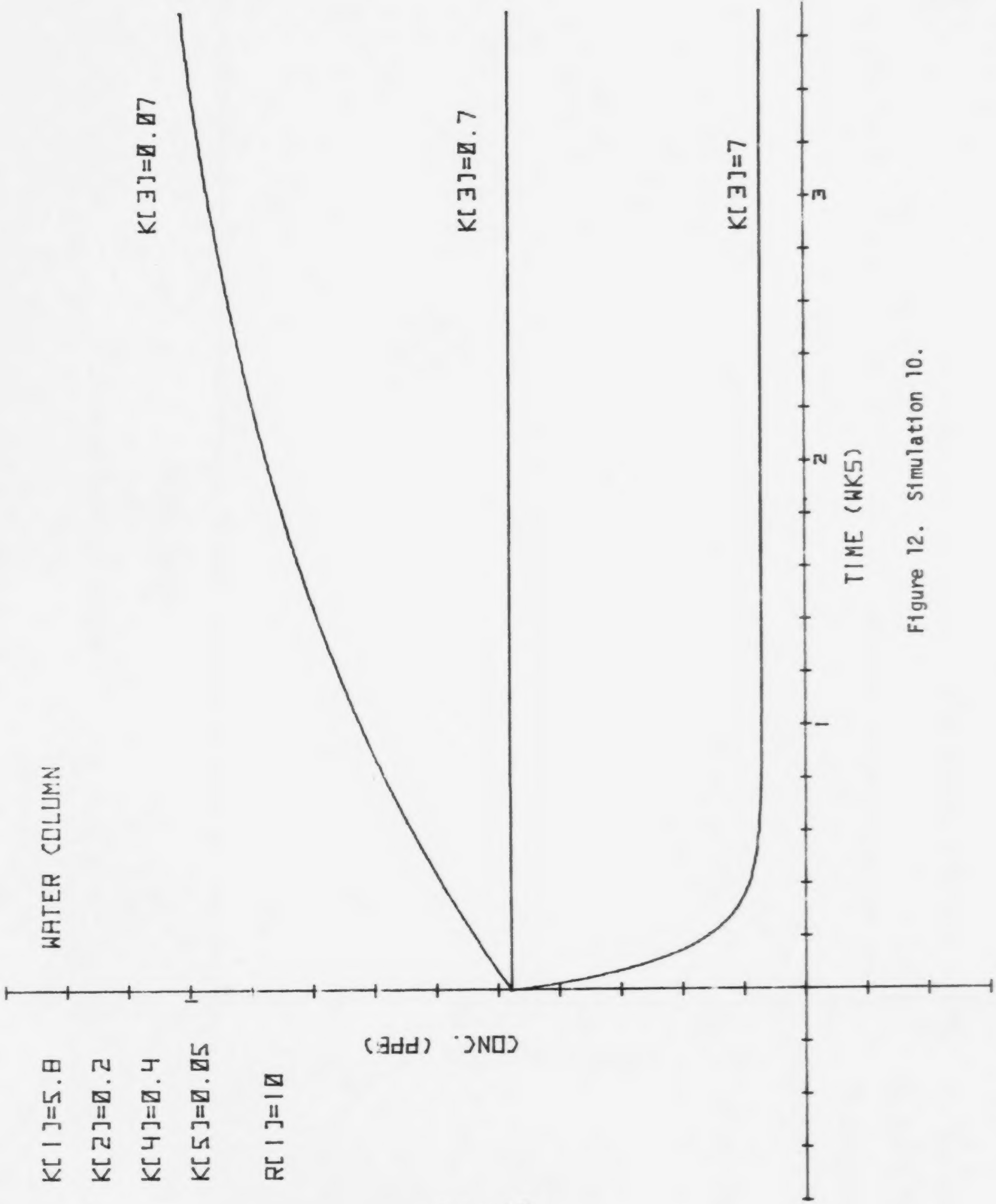


Figure 12. Simulation 10.

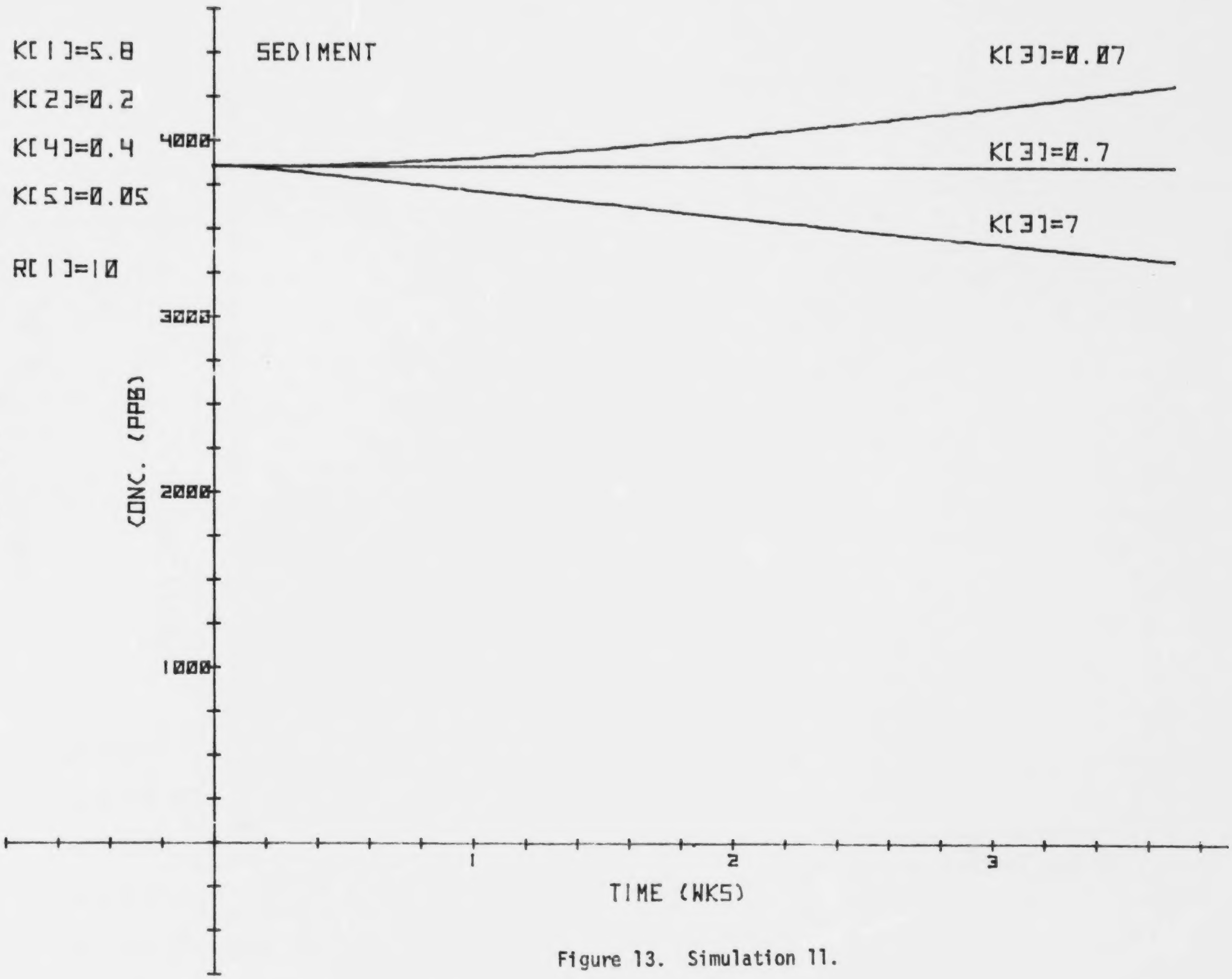


Figure 13. Simulation 11.

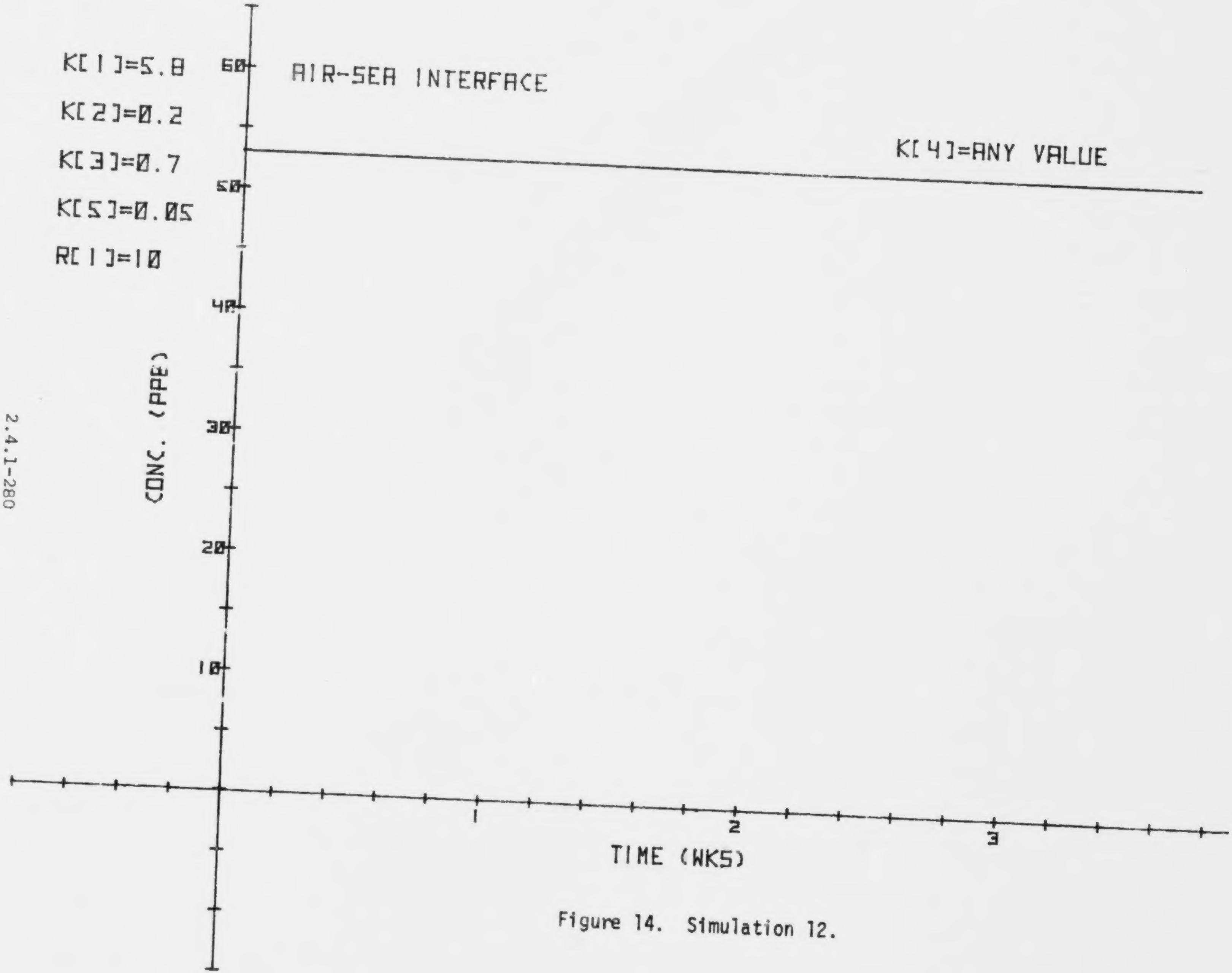
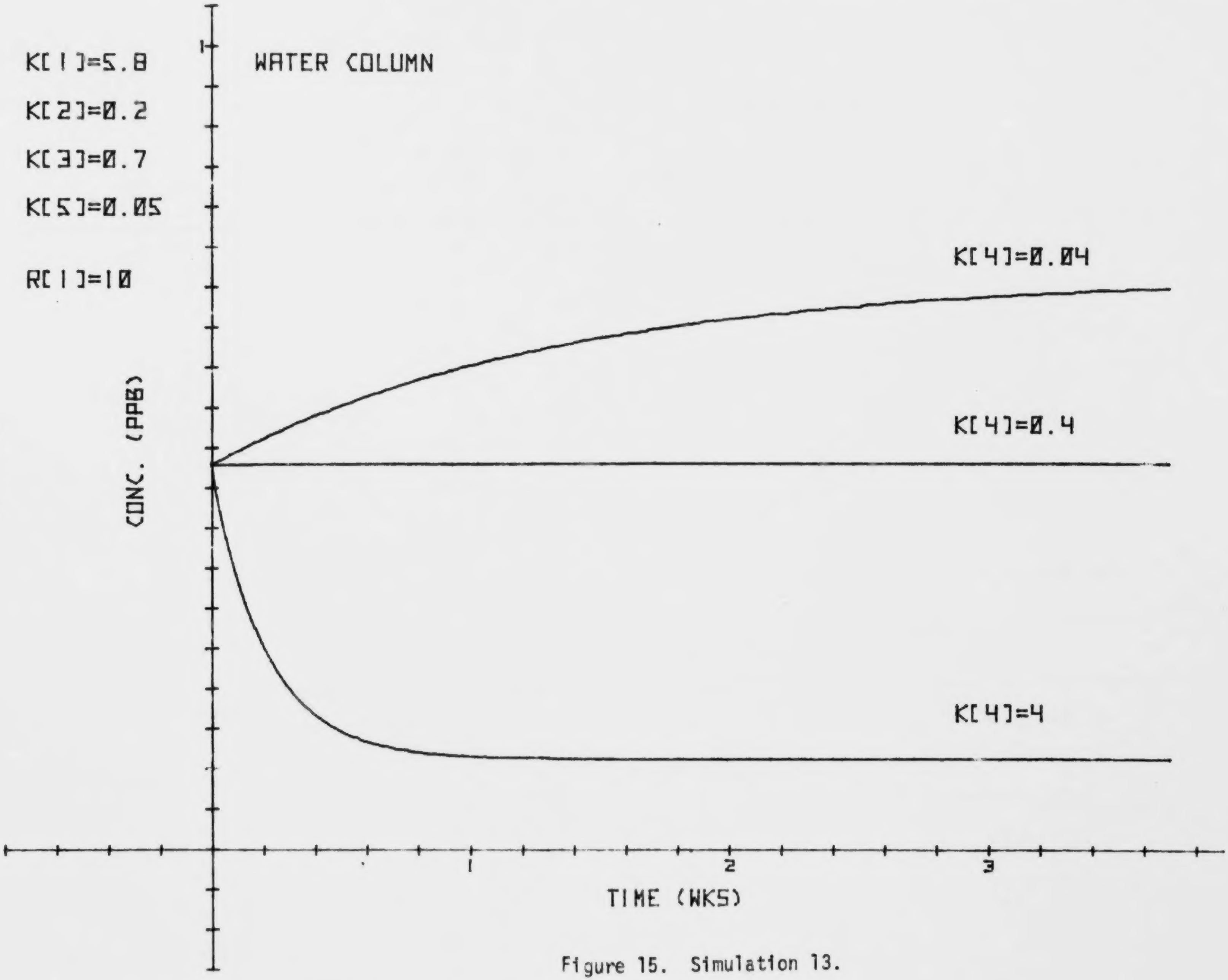


Figure 14. Simulation 12.



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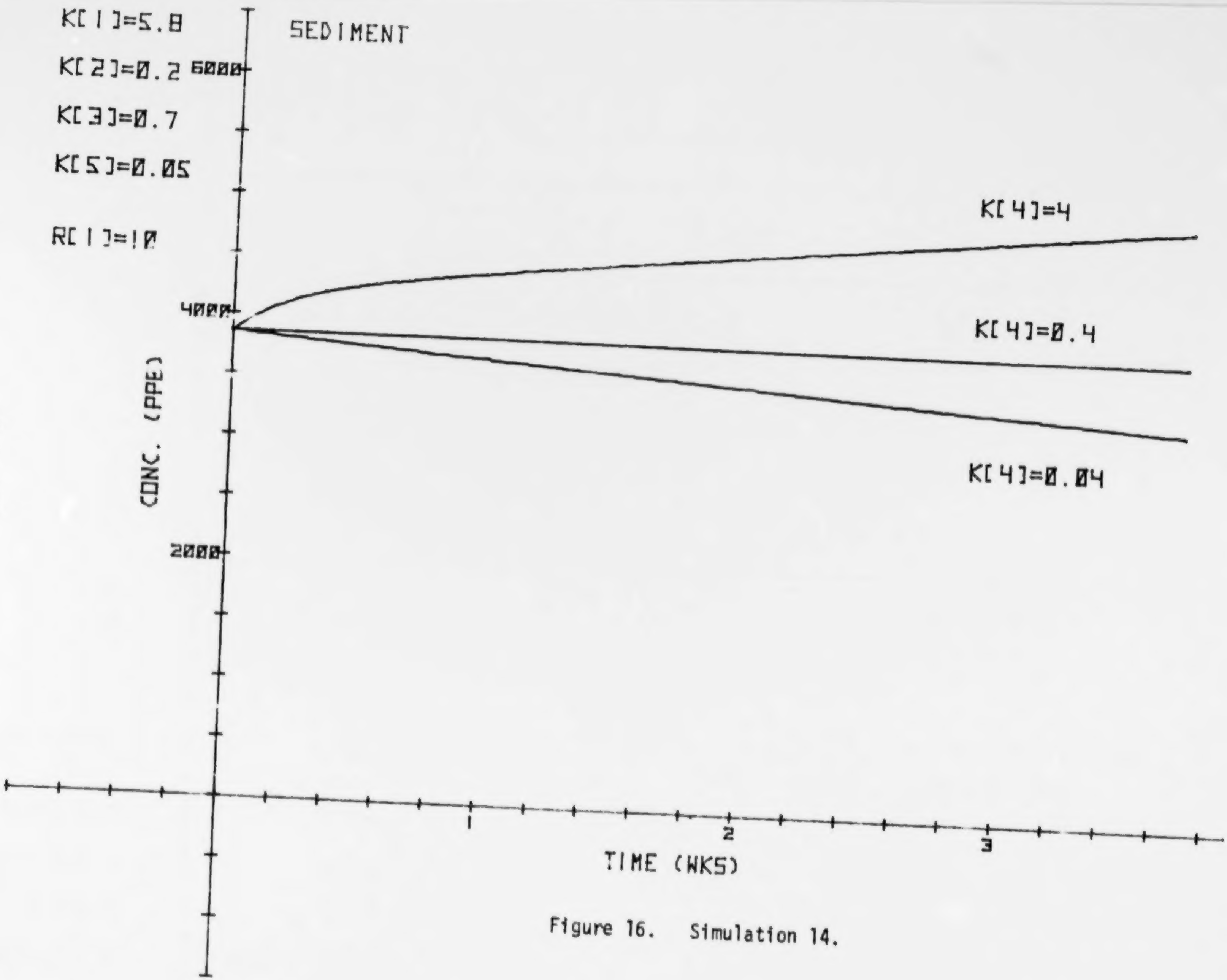
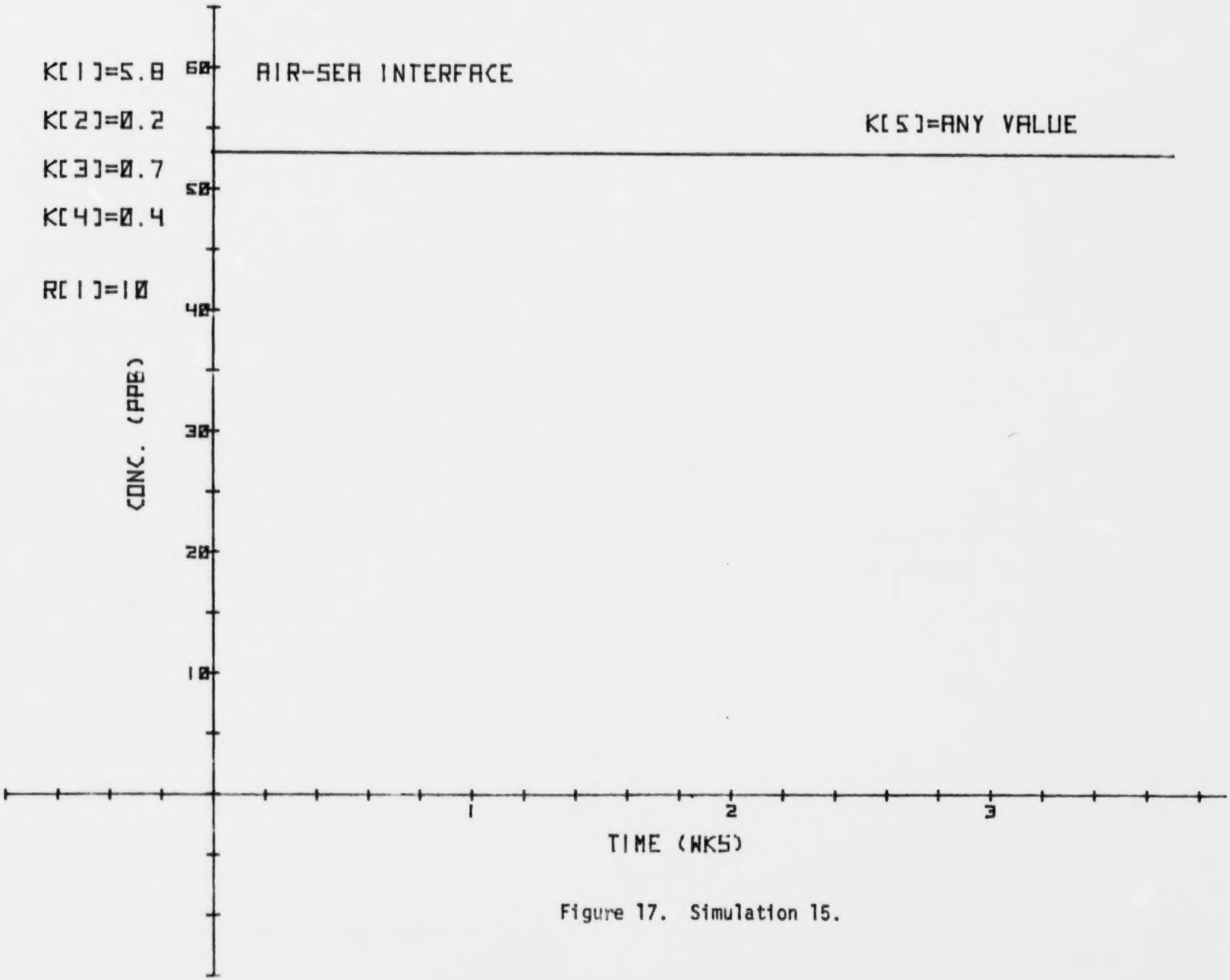


Figure 16. Simulation 14.



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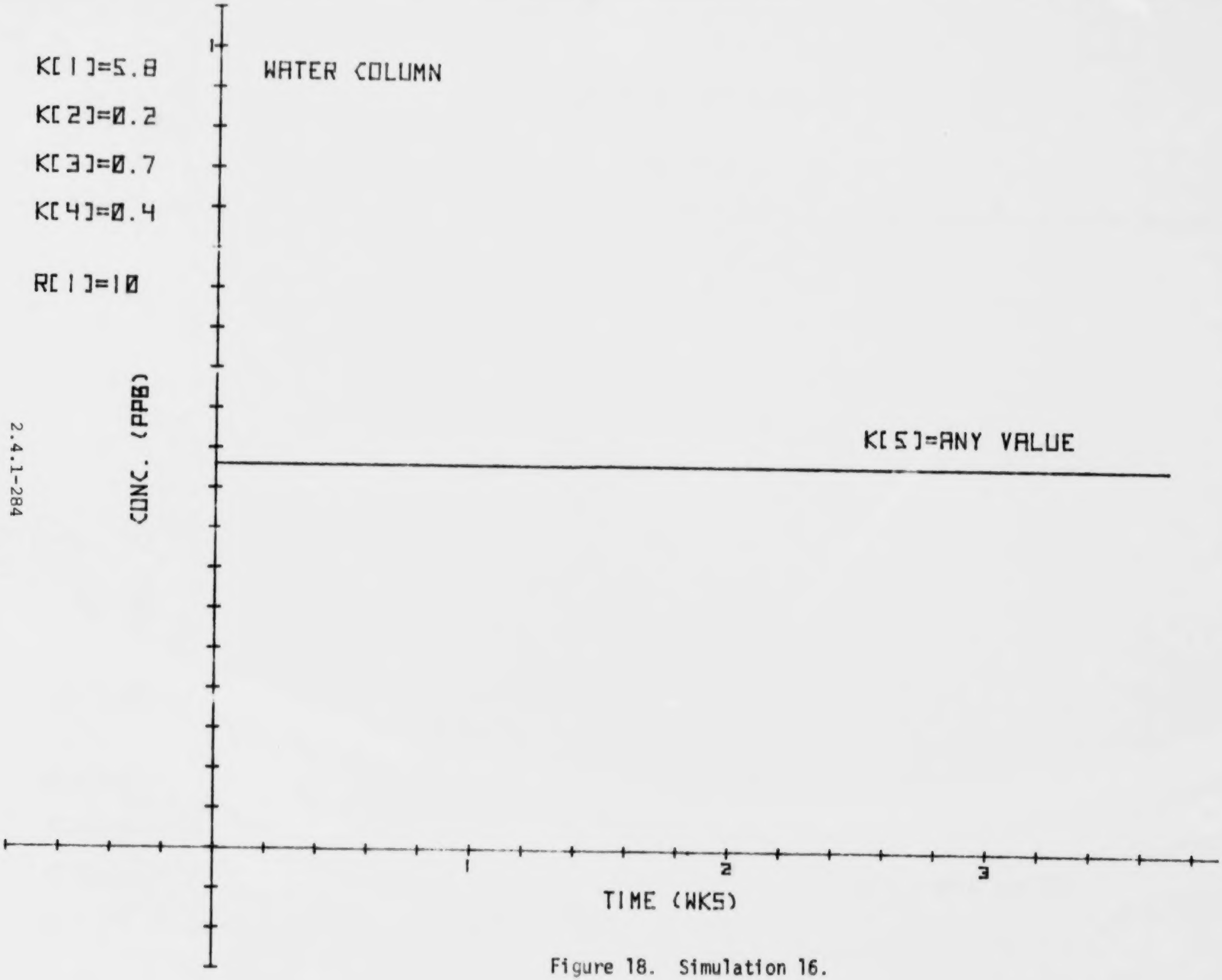

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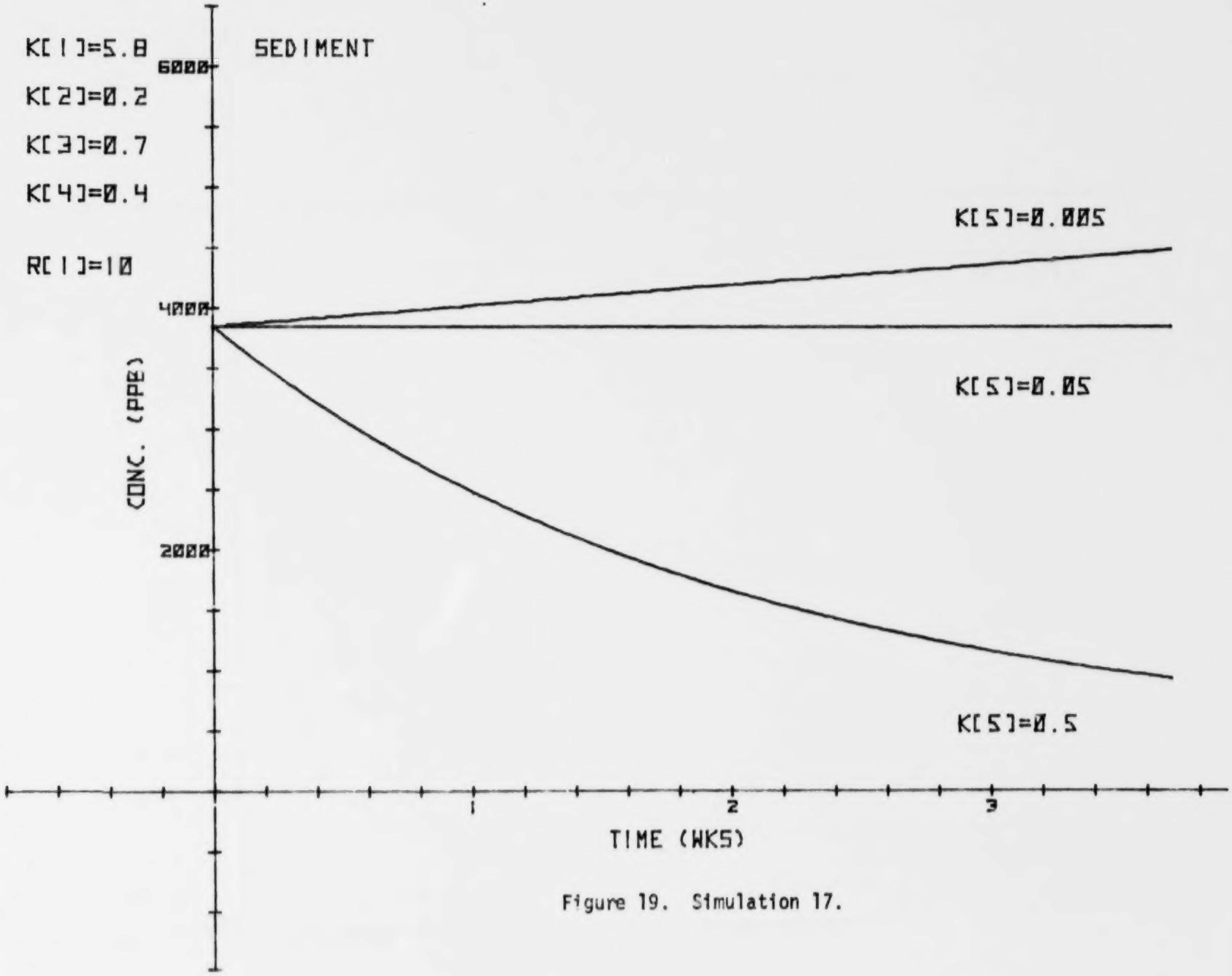

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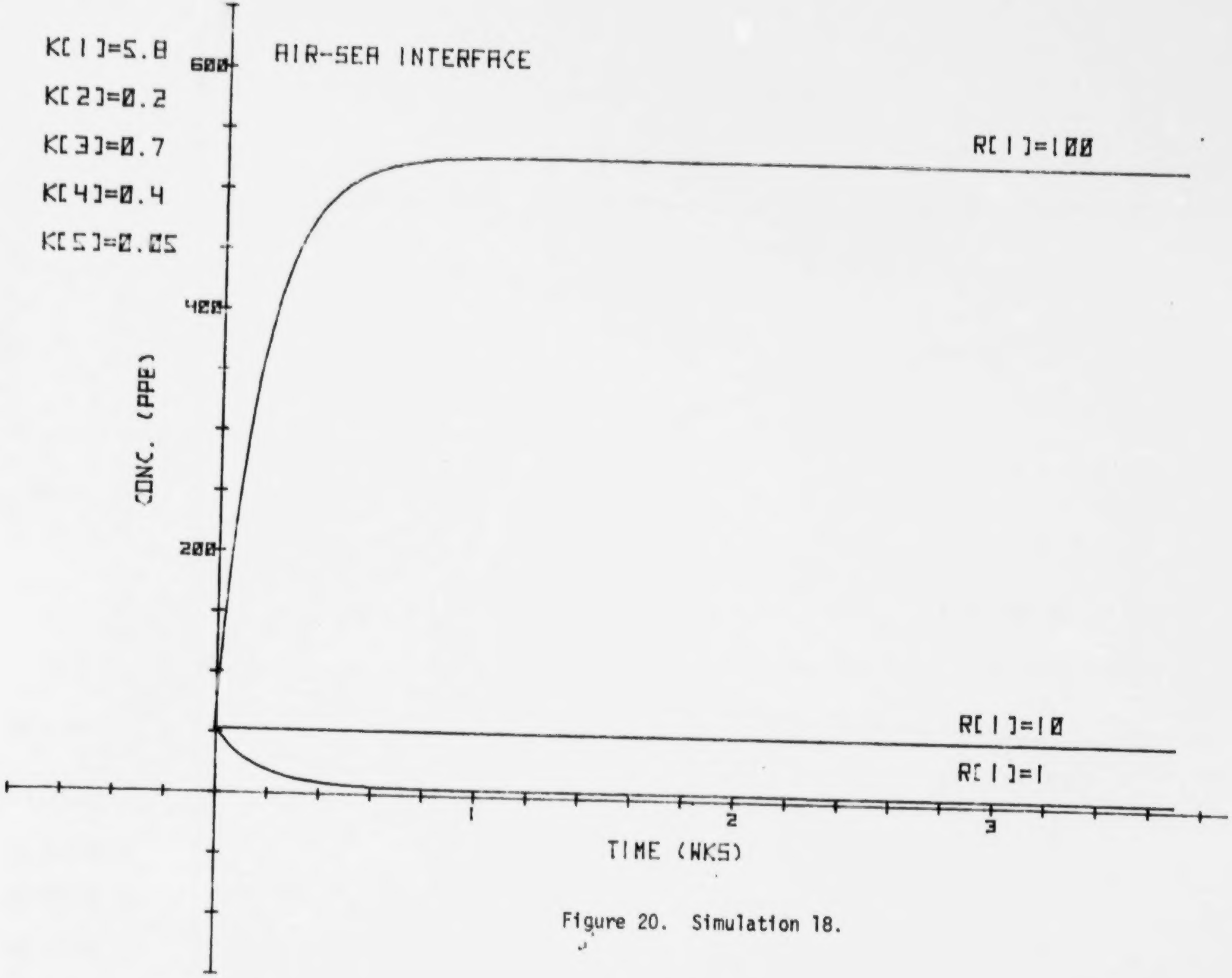
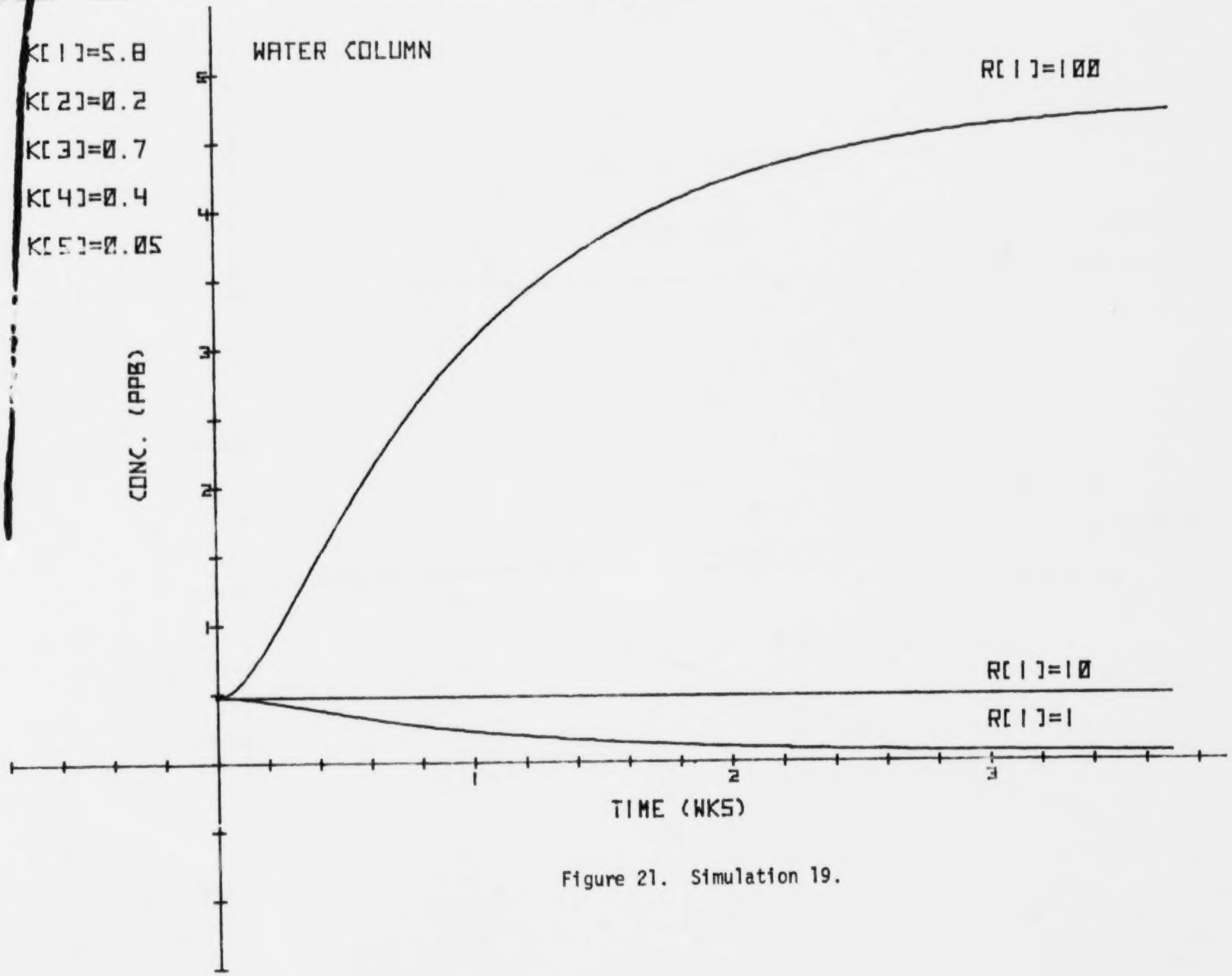


Figure 20. Simulation 18.



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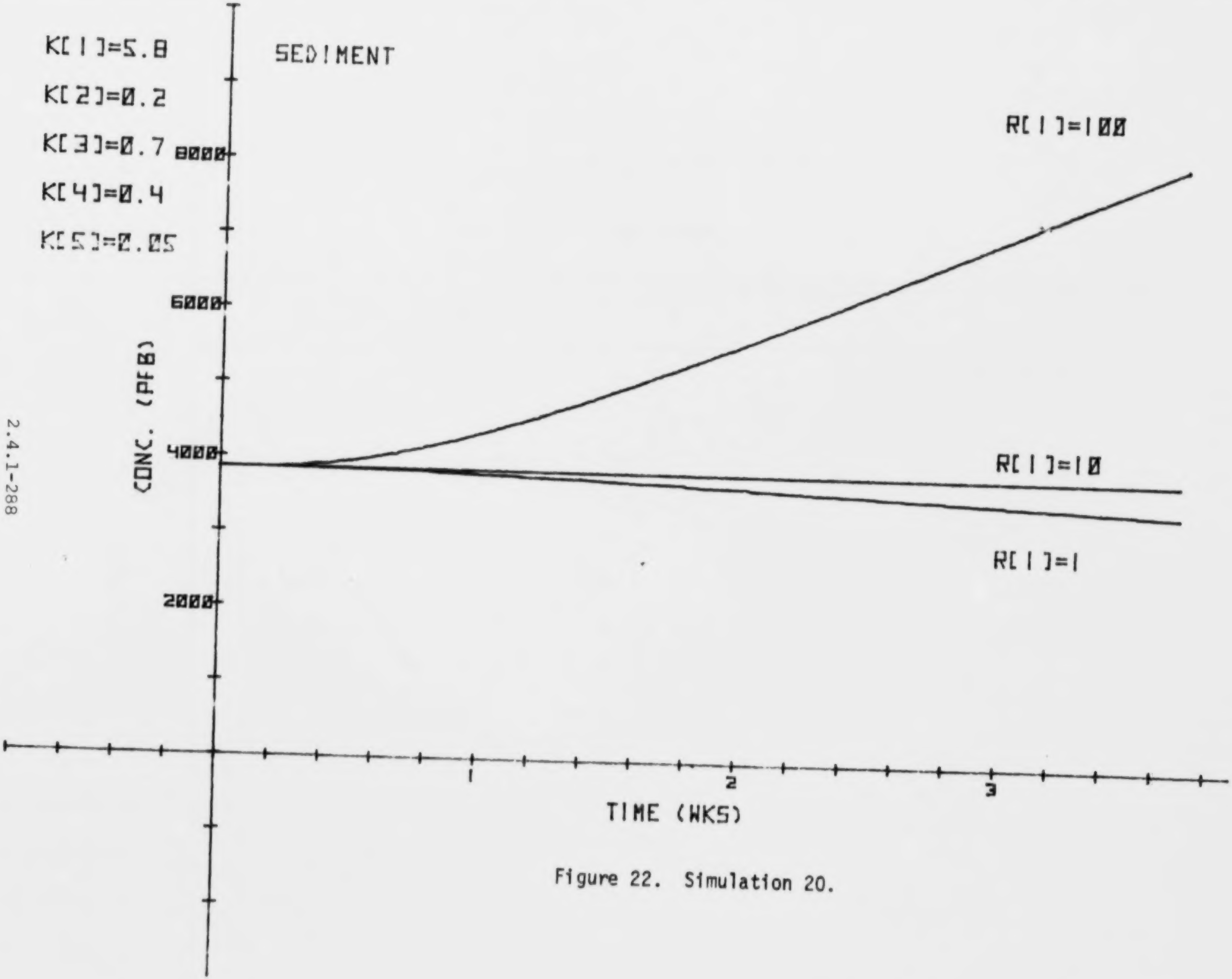

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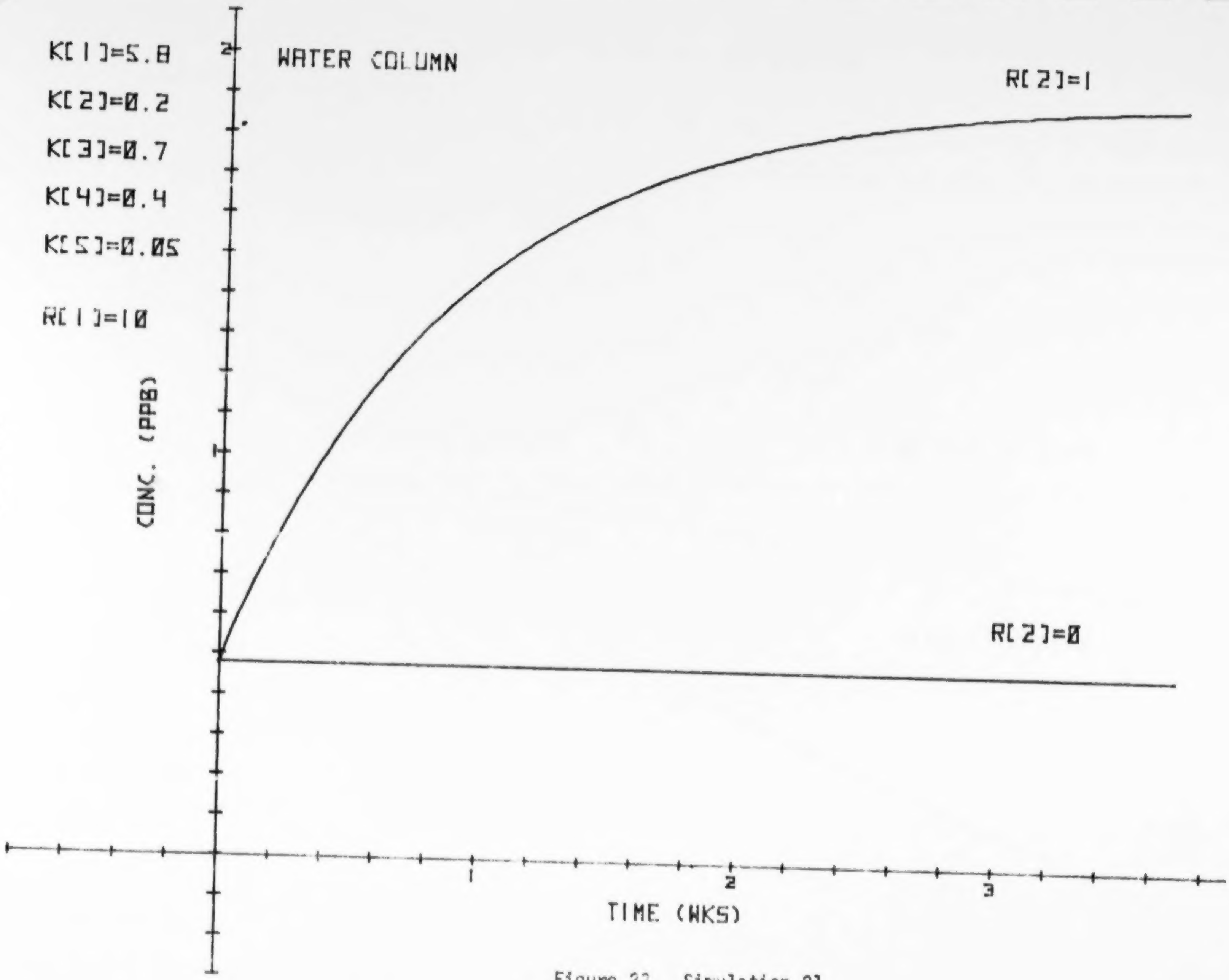

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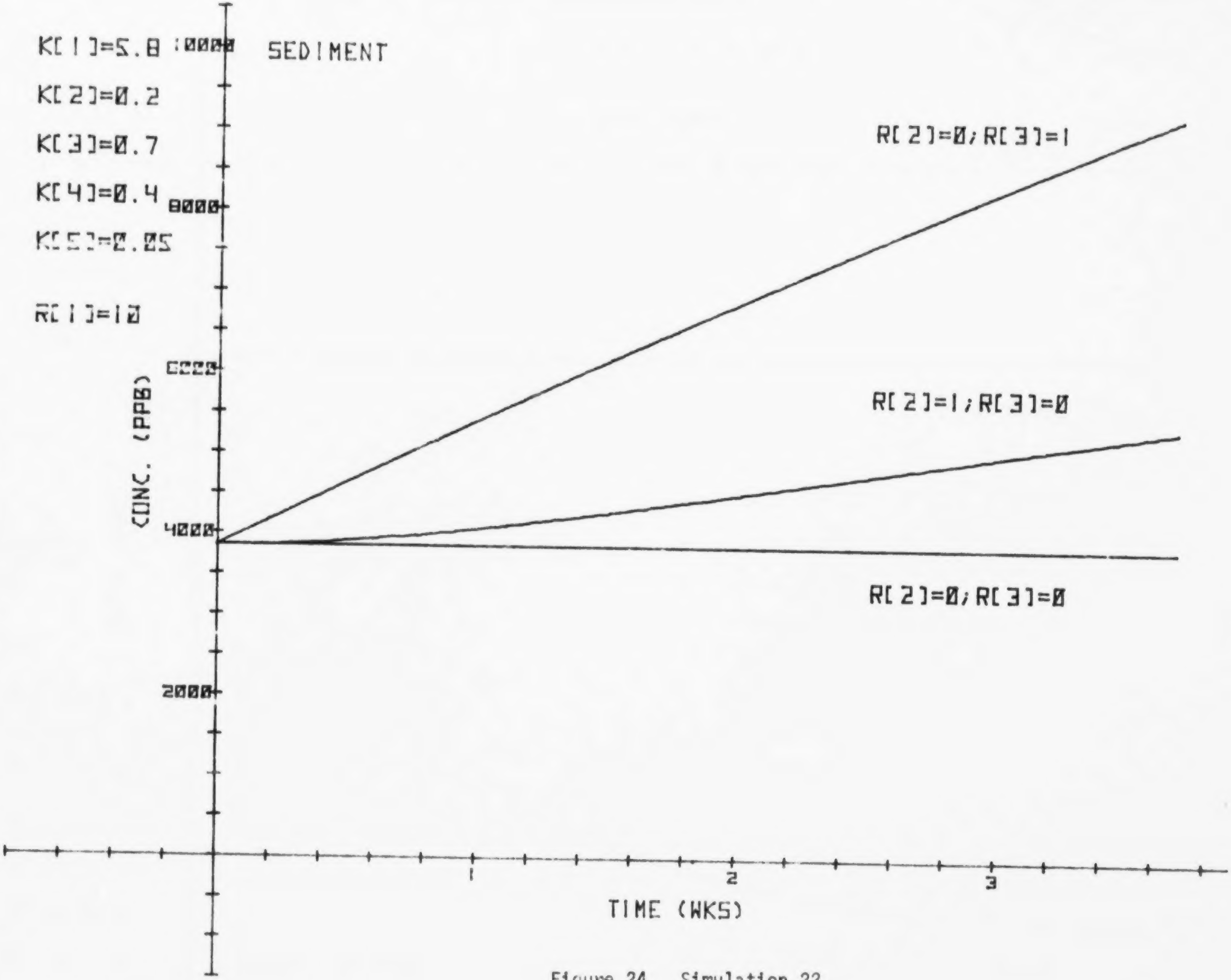

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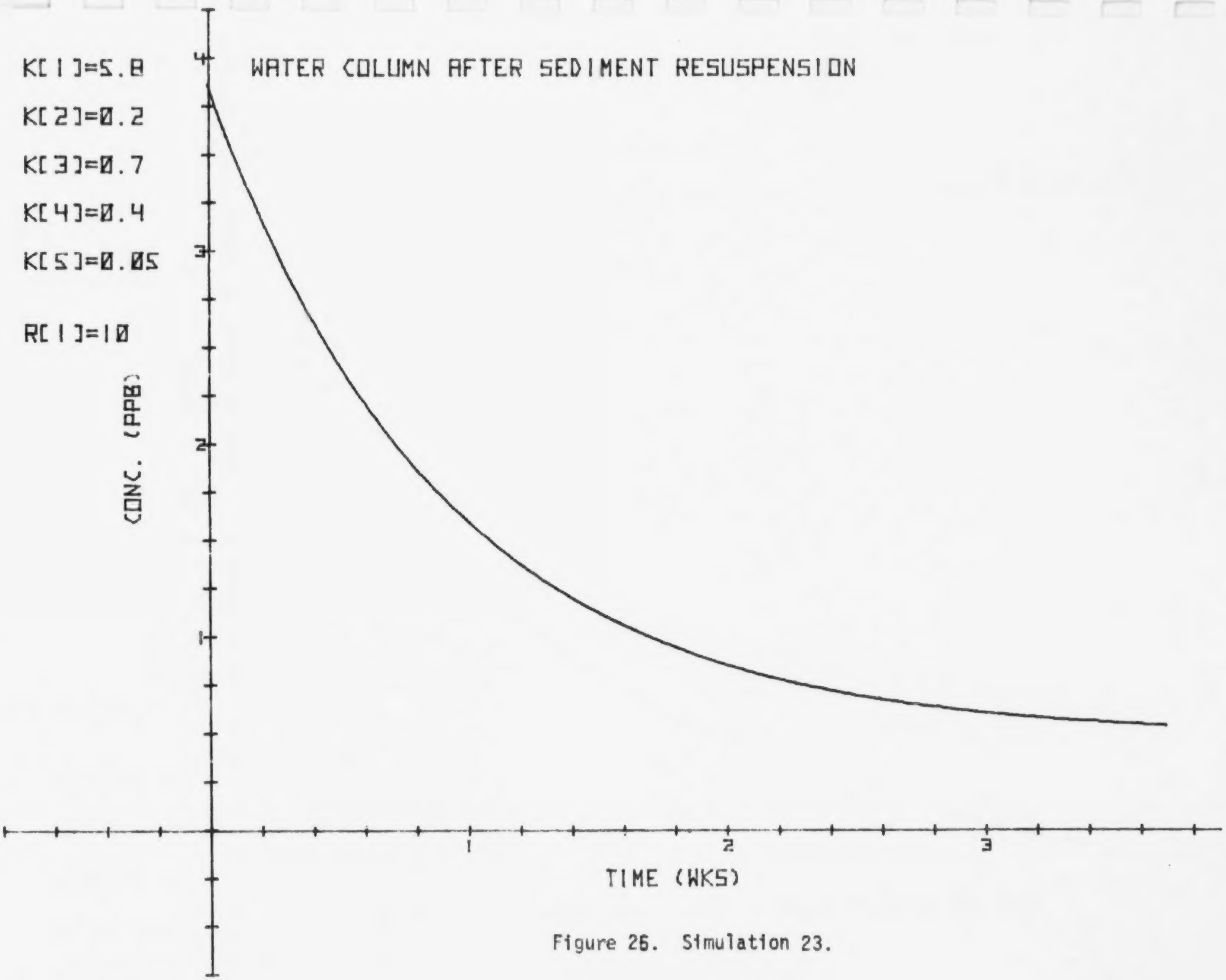

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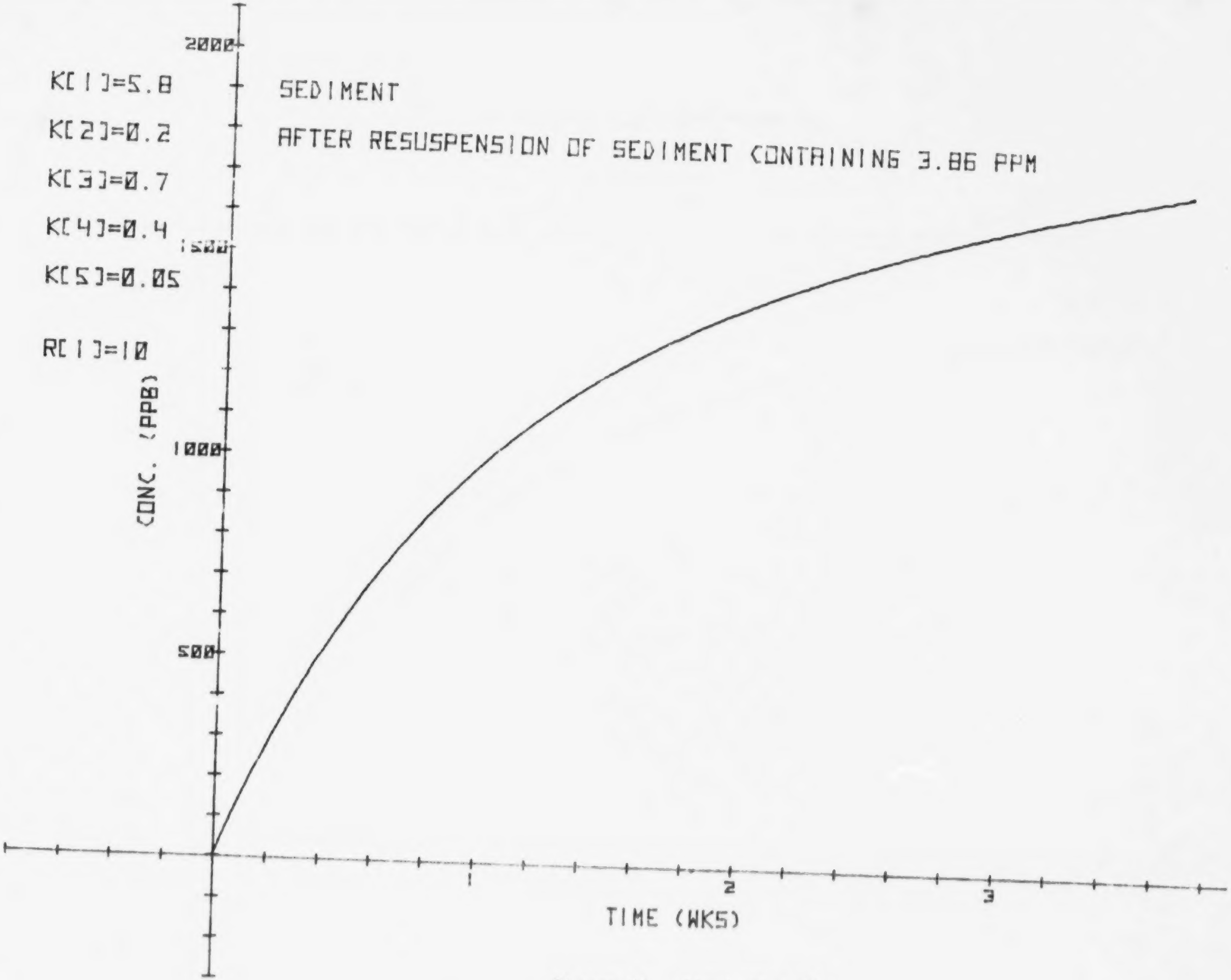

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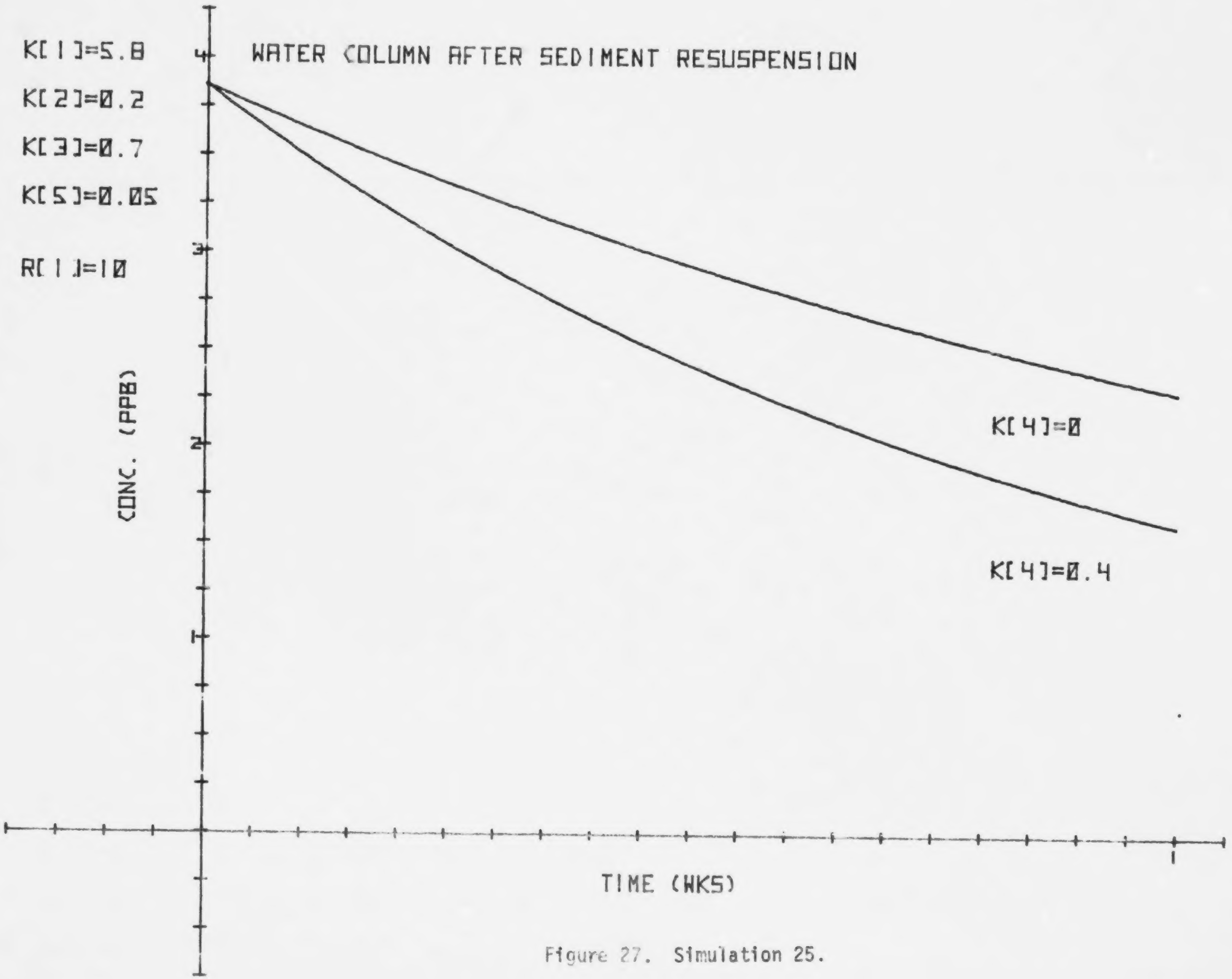

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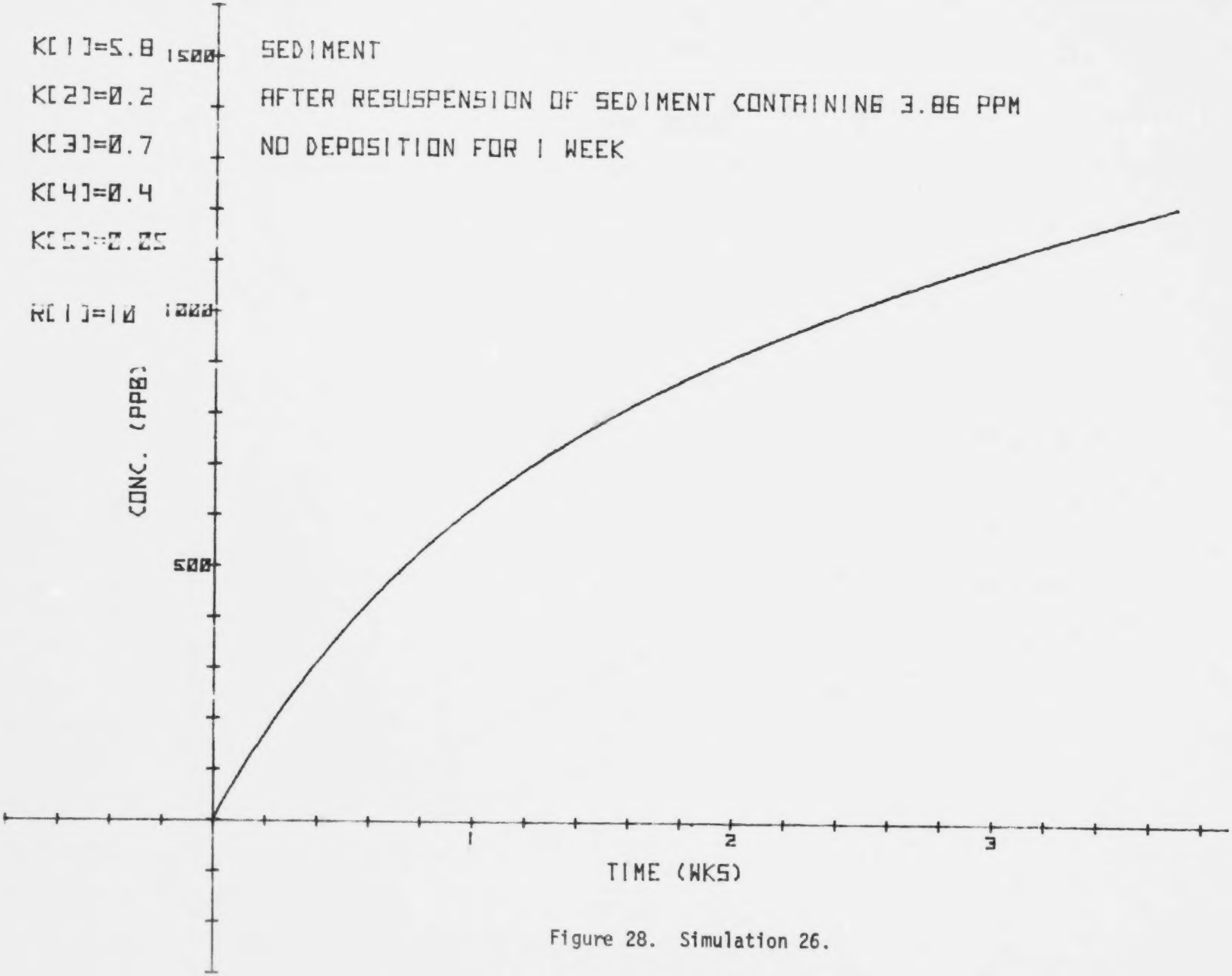

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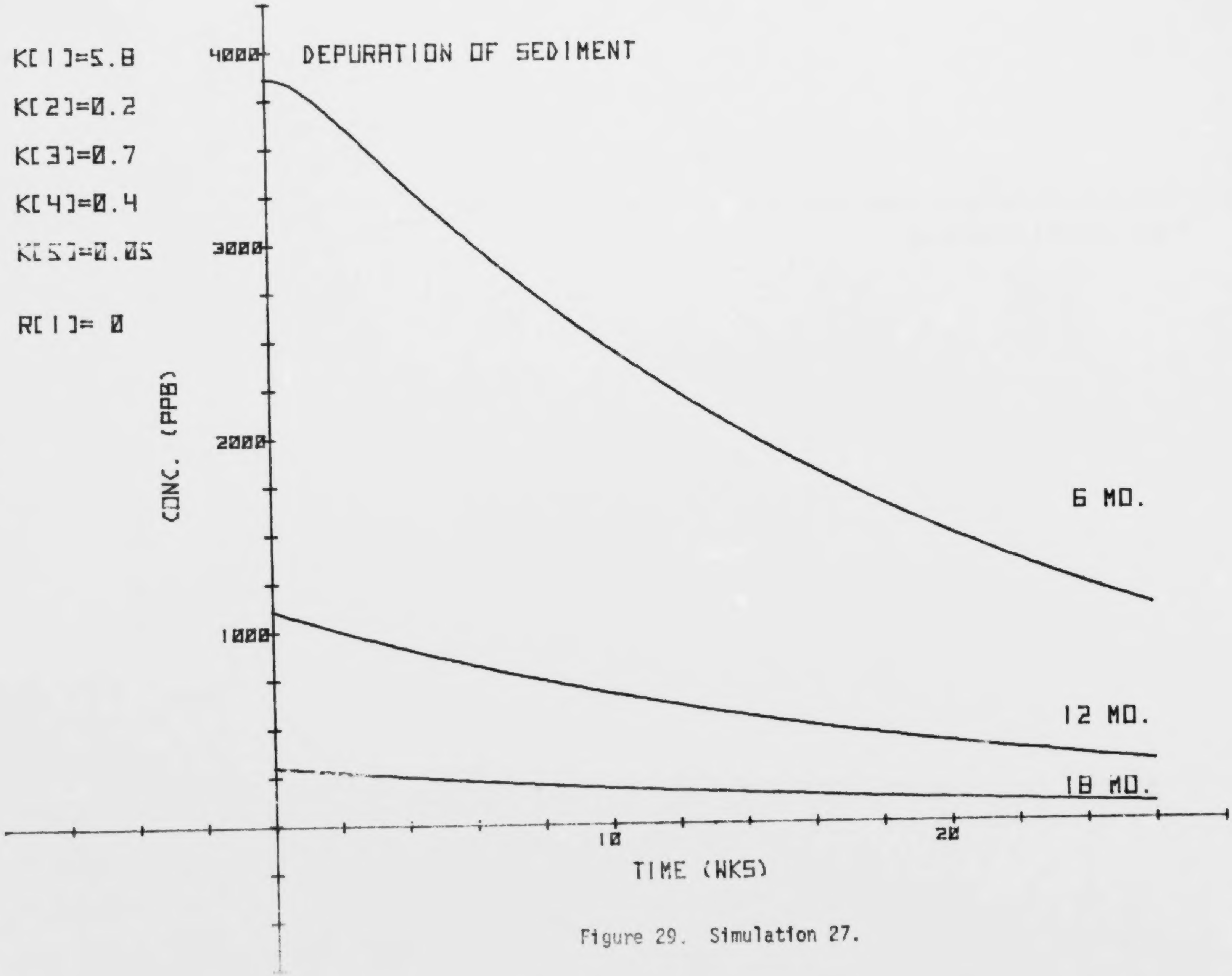

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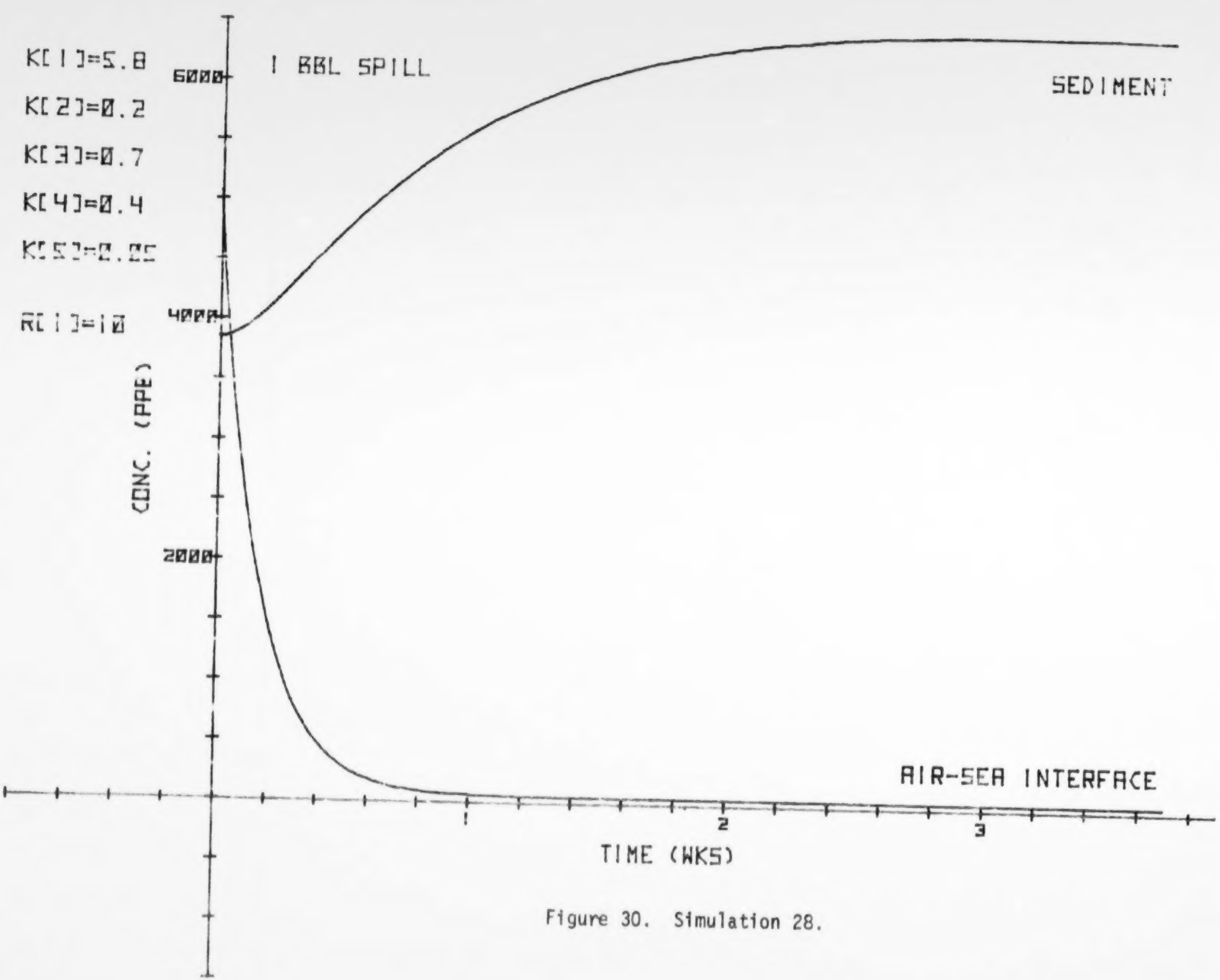

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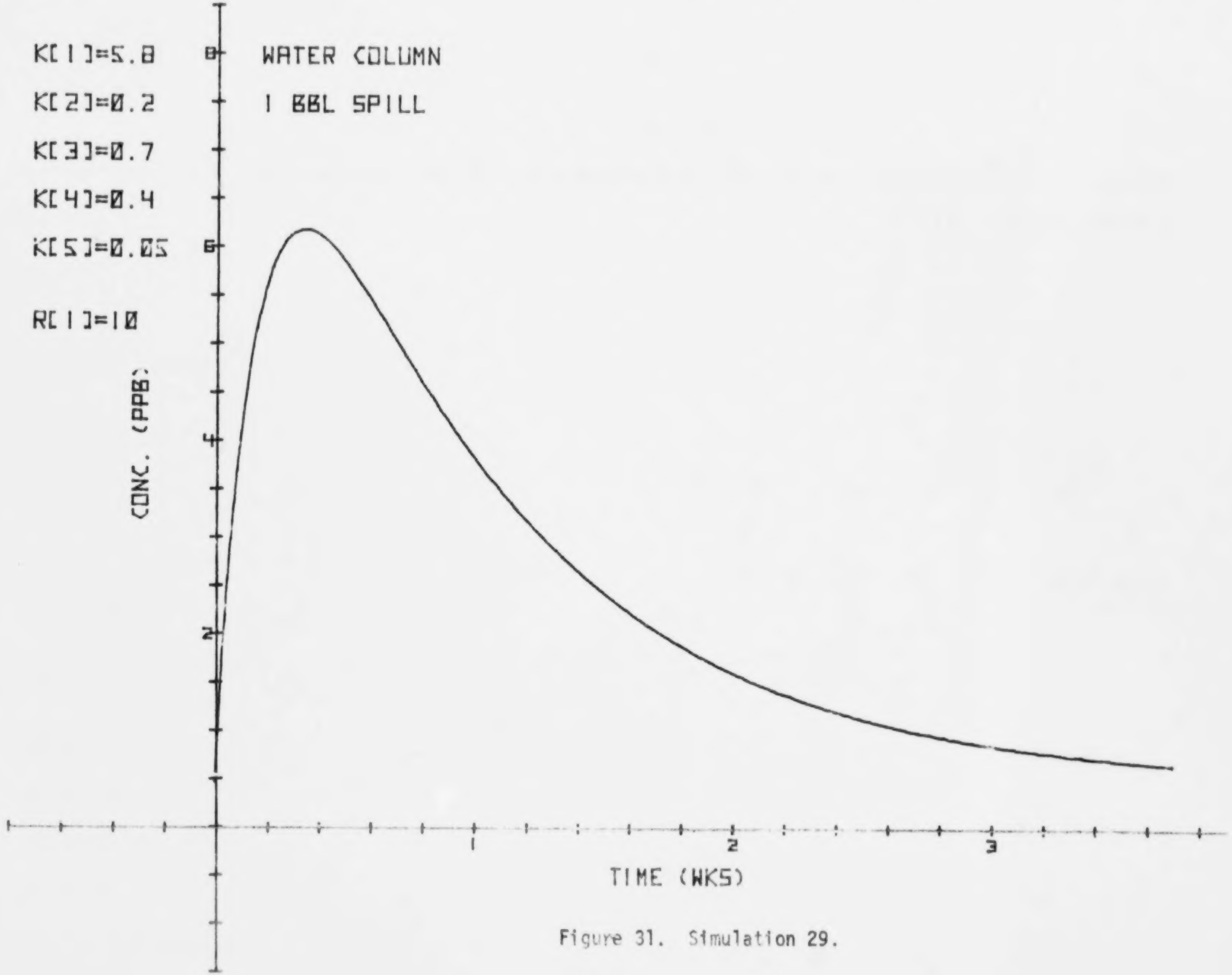
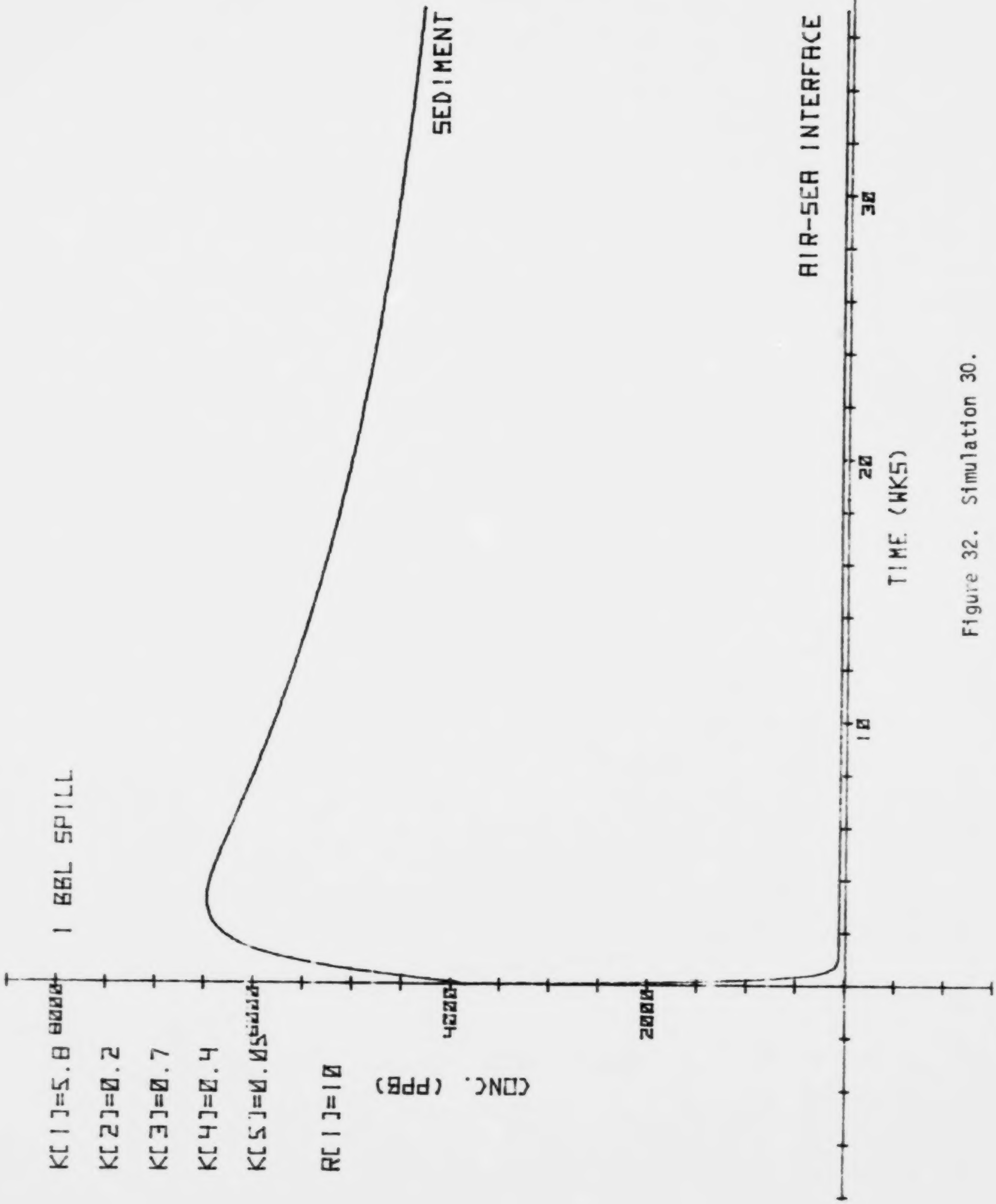


Figure 31. Simulation 29.



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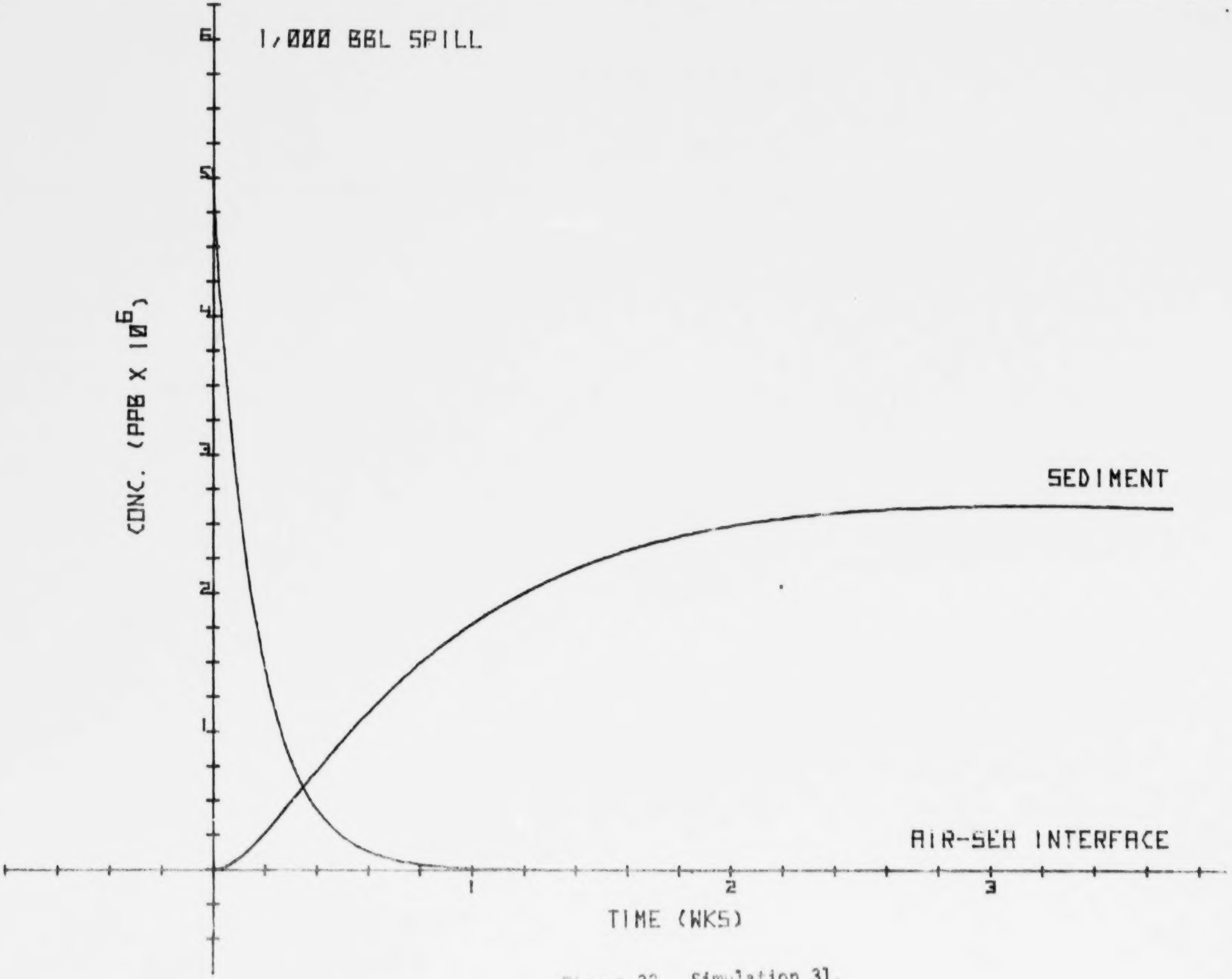

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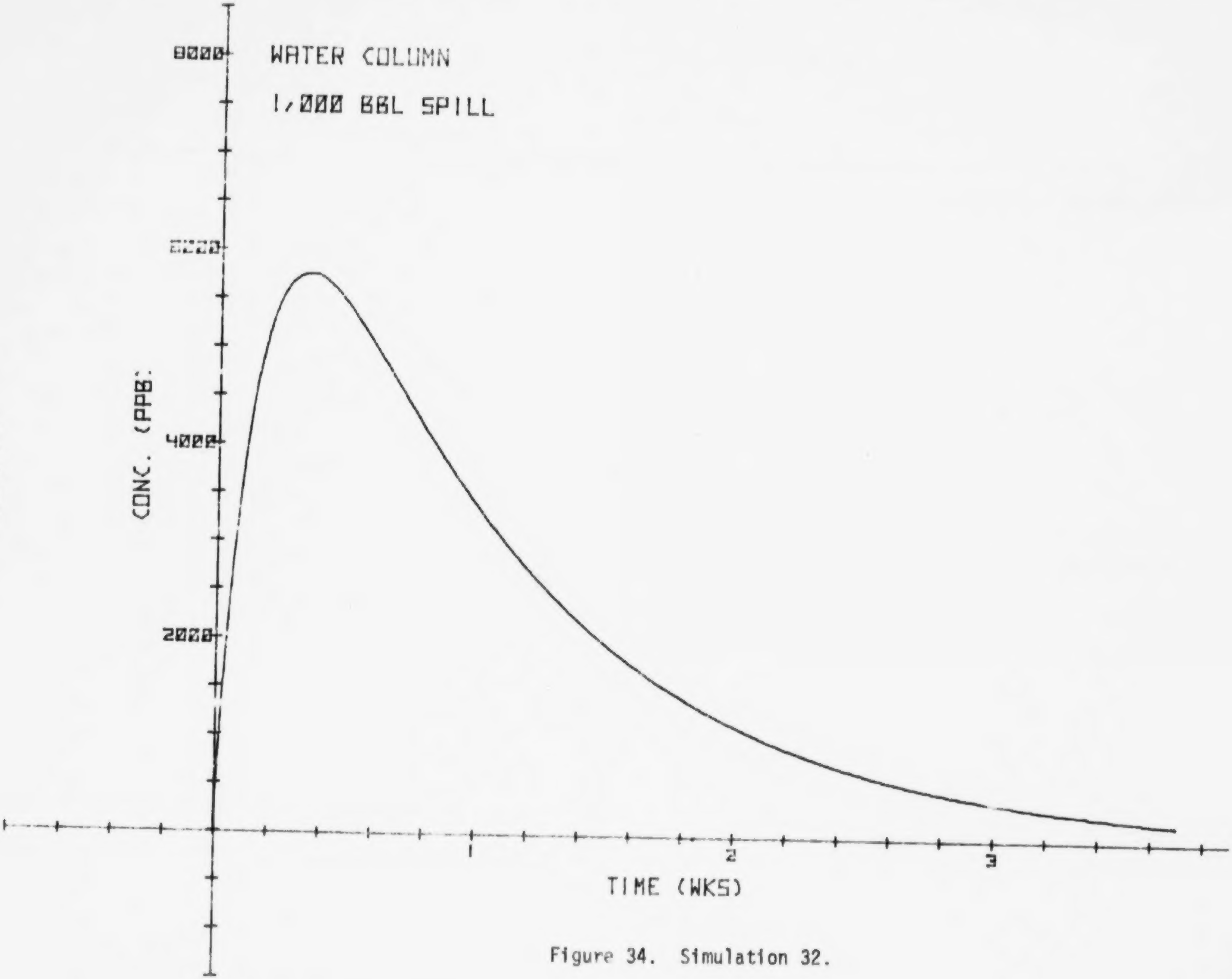

Figure 34. Simulation 32.

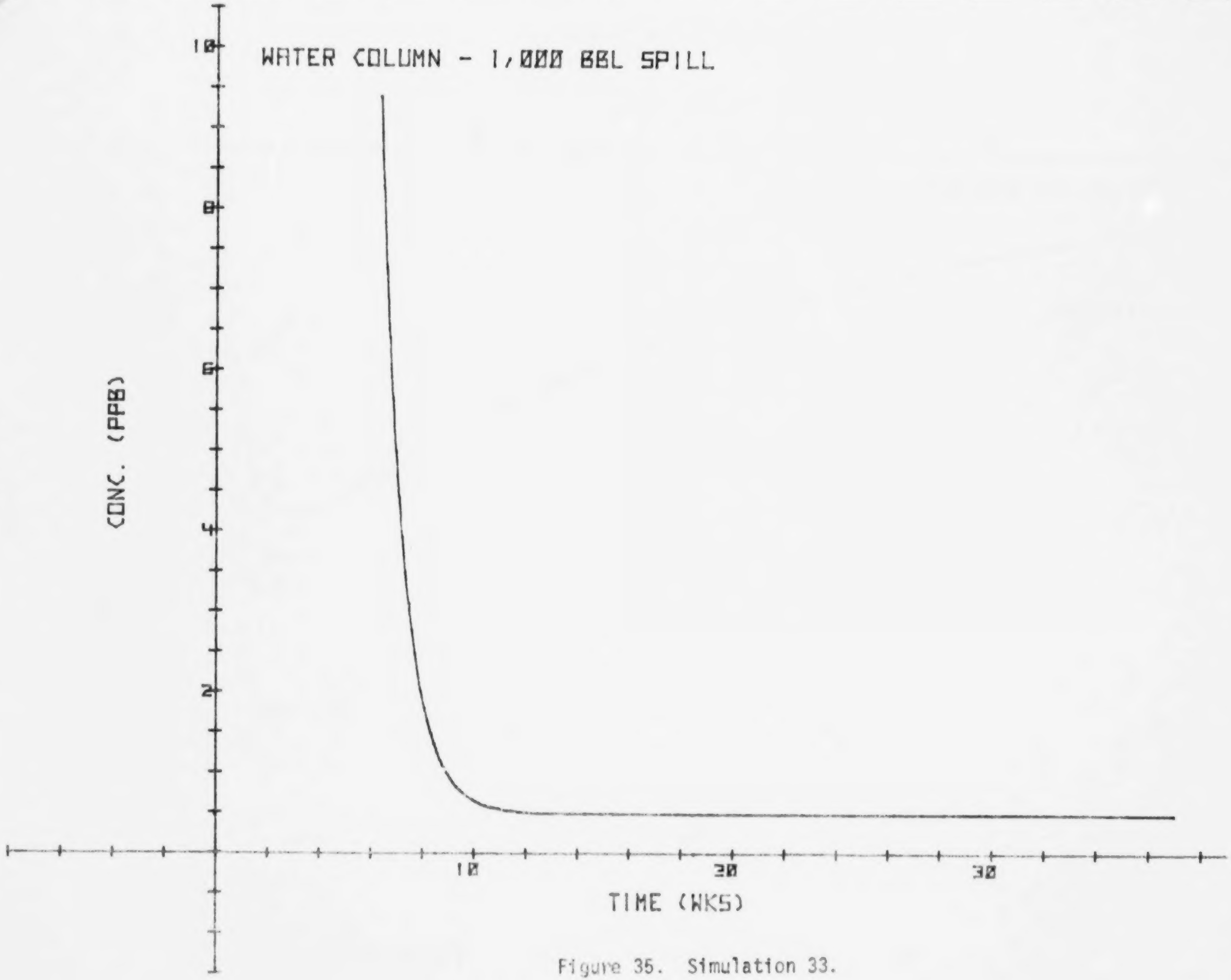

Figure 35. Simulation 33.

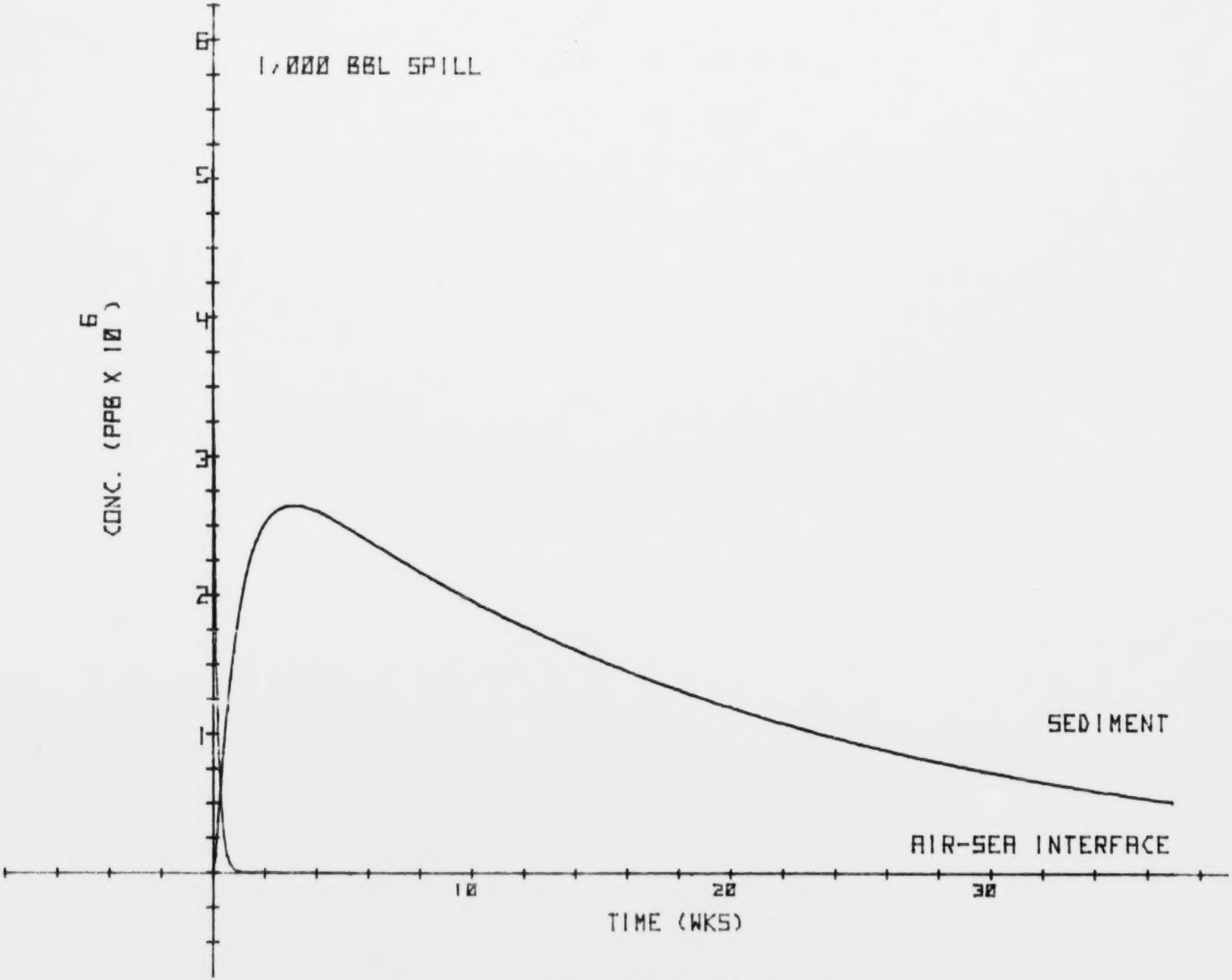

Figure 36. Simulation 34.